NOAA Technical Report NOS OCS 15

NOS EXPERIMENTAL NOWCAST/FORECAST SYSTEM FOR THE PORT OF NEW YORK/NEW JERSEY (NYEFS): REQUIREMENTS, OVERVIEW, AND SKILL ASSESSMENT

Silver Spring, Maryland
October, 2002

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Office of Coast Survey
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
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EXECUTIVE SUMMARY

This document describes the Port of New York/New Jersey Water Level and Current Experimental Model Forecast System and an assessment of its skill. The system, based on a hydrodynamic model, uses near real-time oceanographic and atmospheric observations and forecasts to produce water level and current nowcasts and forecasts throughout the entire model domain, which includes New York Harbor and its estuarine vicinity. In addition to the near real-time information and astronomical tide predictions at a number of gage locations, the mariners navigating in the Harbor can access the model system generated information to improve navigational safety and to optimize cargo operations.

The needs for developing such a model system are analyzed and the model system requirements are also assessed based on a survey of local maritime pilots. The model system structures and operational procedures are described in this document.

The model system skill assessment scenarios specified by NOS (1999) include the astronomical tide simulation, the model system test nowcasts and forecasts, and the pseudo-operational nowcasts and forecasts. The primary statistics used to assess the model performance include: the Central Frequency (CF) - to measure the model errors from a specified target; the Positive Outlier Frequency (POF) and the Negative Outlier Frequency (NOF) - to describe how often the model system either over or under predicts; Maximum Duration of Positive Outliers (MDPO) and Maximum Duration of Negative Outliers (MDNO) - to describe how long the model system either over or under predicts. The skill assessment of the astronomical tide simulation and the model hindcasts (in place of test nowcasts/forecasts) are described in Wei and Chen (2001). The results from the experimental model system nowcast/forecast are summarized as follows.

(1) **Water Level at the Bayonne Bridge and The Battery**

Nowcasts: All statistics meet NOS (1999) standard
Forecasts: Do not meet NOS (1999) but better than astronomical tide predictions
Bayonne Bridge: CF > 80%, POF and NOF about 1% to hour 6
CF about 75% at hour 24 and POF and NOF about 2%.
The Battery: CF about 75%, POF < 1%, NOF about 3% to hour 6
CF about 71%, POF about 1%, NOF about 3% to hour 24

(2) **Currents**

Nowcasts: Do not meet NOS (1999) at Bergen Point. Meet NOS (1999) at The Narrows
Bergen Point: Speed: CF(76%), POF(9%), NOF(0%), MDPO & MDNO < 3 hours
Direction: CF(86%), POF & NOF < 1%, MDPO & MDNO < 1 hour
The Narrows: Speed: CF(95%), POF & NOF< 1%, MDPO & MDNO < 3 hours
Direction: CF(94%), POF(2.5%), NOF < 1%, MDPO & MDNO < 15 hours
Forecasts: Do not meet NOS (1999) at Bergen Point. Meet NOS (1999) at The Narrows
Bergen Point: Speed: CF(76%), POF(9%), NOF(0%), MDPO & MDNO < 22 hours
Direction: CF(85%), POF & NOF < 1%, MDPO & MDNO < 8 hours
The Narrows: Speed: CF(95%), POF & NOF< 1%, MDPO & MDNO < 2 hours
Direction: CF(94%), POF(2%), NOF < 1%, MDPO & MDNO < 14 hours

1. INTRODUCTION

Mariners navigating in New York Harbor (Figure 1) and nearby estuaries rely on astronomical tide predictions (NOS Tide and Tidal Current Tables) and real-time water level and current information (PORTS - Physical Oceanographic Real-Time System) at selected locations maintained by the National Ocean Service (NOS) of NOAA. However, these gages provide limited information to the users, and the astronomical tide predictions do not account for the non-tidal signals induced either by meteorological or river discharge influences.

A numerical model-based forecast system is the most effective and accurate tool to account for the effects of the non-tidal signals on the water levels and currents in the Harbor. The Port of New York/New Jersey Experimental Forecast Model System (NYEFS) is designed to provide accurate water level and current predictions to the marine community in the New York Harbor region (Figure 1.1). The needs and requirements for developing the system as a forecast component of NOS's PORTS are described in Chapter 2.

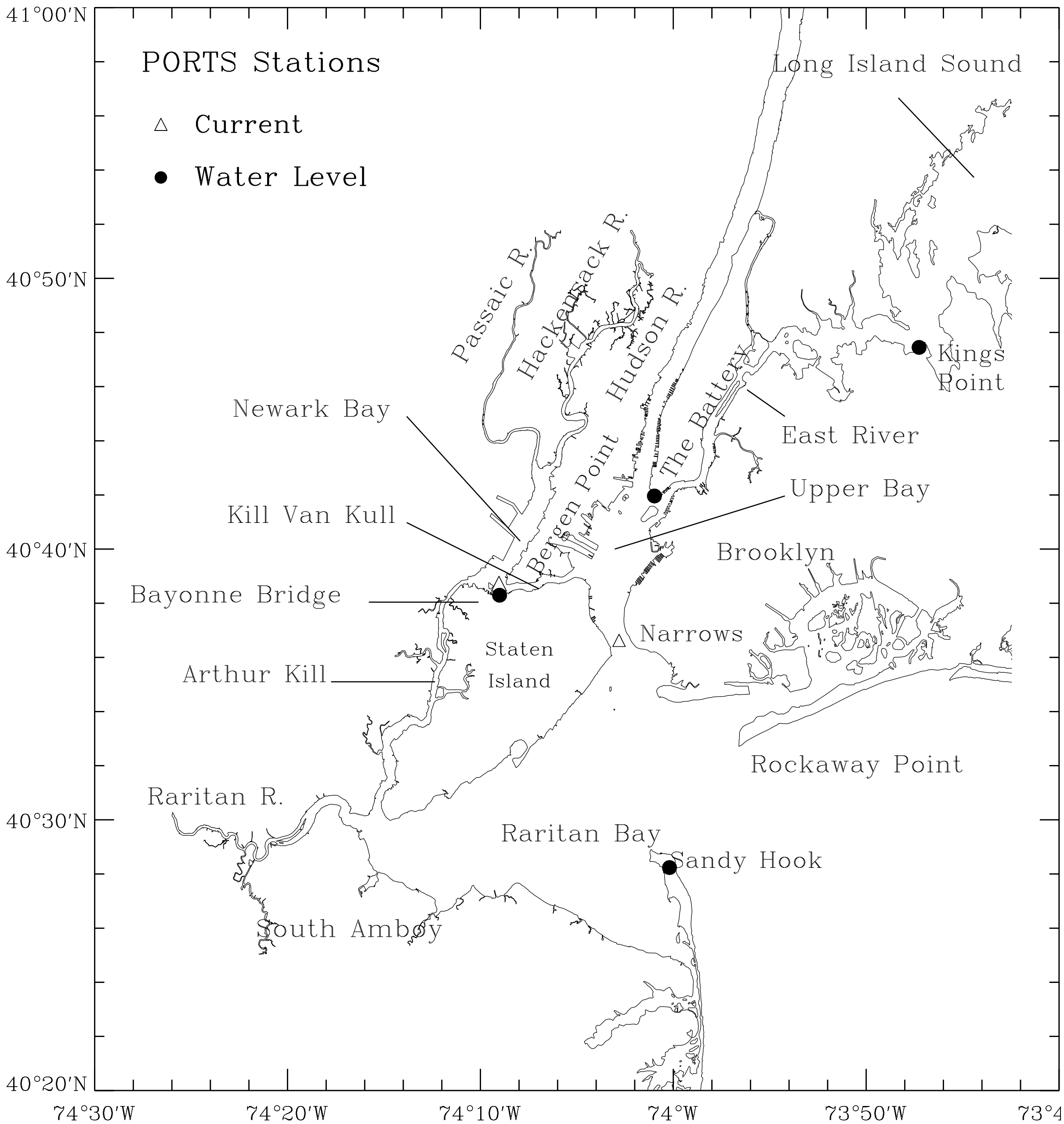
The model system includes a hydrodynamic model component and a suite of software for processing input and output data, including graphic applications. The nowcast/forecast model system operation consists of three components: input data ingestion, model nowcast/forecast, and model data post-processing. Each element is controlled by automated scripts under a Unix environment. The sequential procedures include: gathering and formatting the input data for the hydrodynamic nowcast/forecast simulations, running the nowcast/forecast model, and post-processing the model output to graphically display on the Internet or for dissemination to users via ftp. The system overview is described in Chapter 3.

The hydrodynamic model component of the experimental nowcast/forecast model system has been developed and calibrated (Wei and Chen, 2001) based on a three-dimensional barotropic version of the Princeton Ocean Model (POM, Blumberg and Mellor, 1987). A fine sub-grid model, covering channels and bays critical to navigation, including the Kill van Kull and Bergen Point, has been developed and embedded within and dynamically connected to the coarse grid model using a one-way coupling technique. Figure 1.2 shows the model grids. The model system provides hourly nowcasts and 36 hour forecasts of water levels and currents within the New York Harbor.

Since April of 1999, the experimental system has been implemented and run on NOS's Coast Survey Development Laboratory (CSDL) computer. The model system has been modified to improve its accuracy and reliability. Automated script to handle operational procedures have been modified and updated to accommodate a variety of networking and changes in data types.

This report describes the model performance based on NOS requirements for operational nowcast/forecast systems (NOS, 1999). Skill assessments for tidal simulation and test nowcast assessments have been reported as part of the model documentation in Wei and Chen (2001). Due to 1997 observed data errors at The Battery, the water level test nowcast skill assessment at The Battery was based on four months of observations. A test nowcast simulation conducted using the entire 1998 data shows similar results to the 1997 four month test nowcast skill assessment. Model nowcast/forecast output from the experimental system are saved for skill assessment, which is presented in Chapter 4. This report, in conjunction with the model documentation (Wei and Chen, 2001), completes the Port of New York/New Jersey skill assessment required by NOS (1999).

Figure 1.1. Map showing New York Harbor and major tributaries.



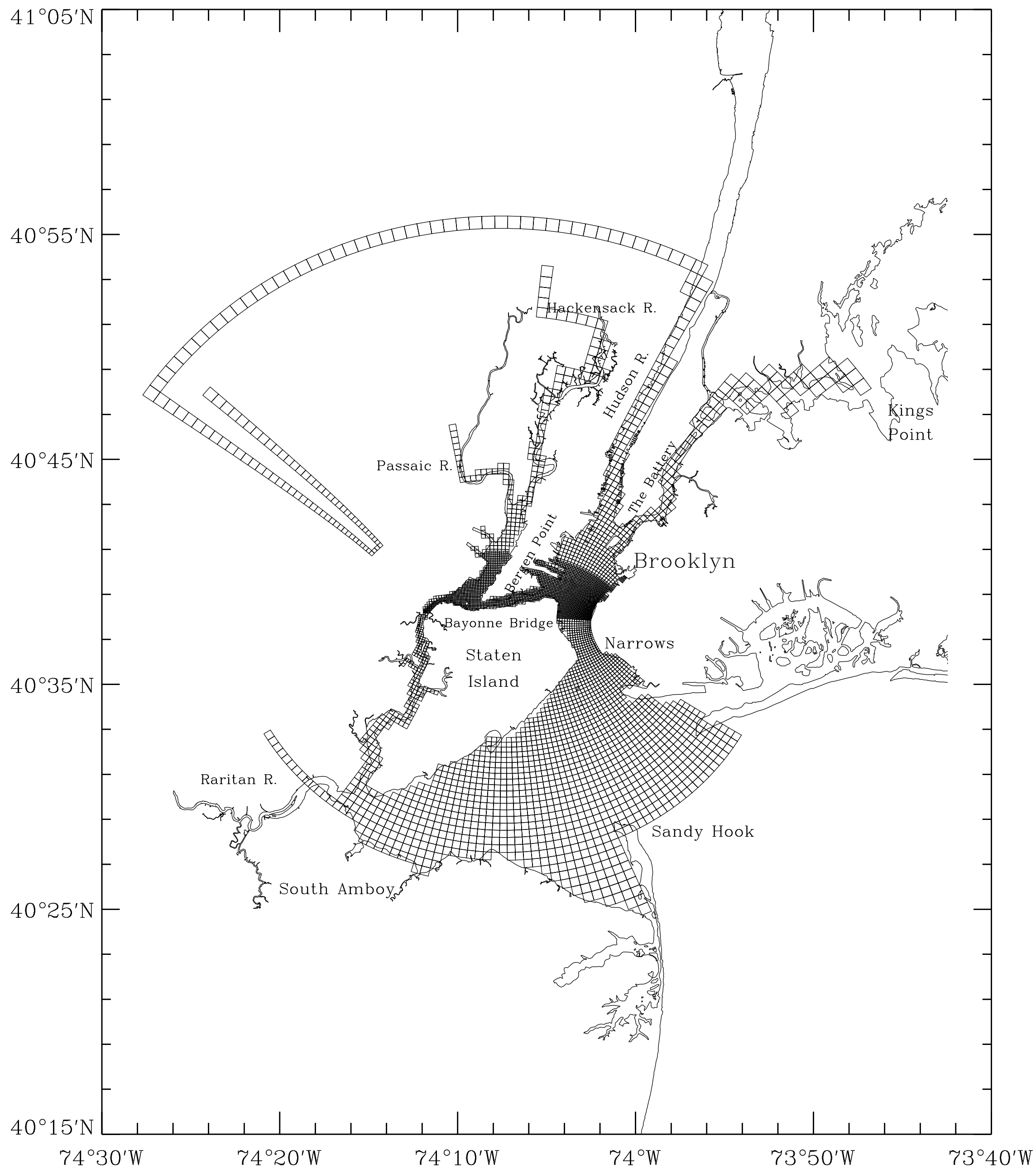


Figure 1.2. NYEFS model grid. Shaded area represents the embedded fine grid.

2. NEEDS ANALYSIS AND REQUIREMENTS ASSESSMENT

Much of the hydrodynamics in the Harbor are determined by coastal fluctuations propagating through the Harbor entrance (Figure 1). The main flow goes through The Narrows; part of the flow north of The Narrows goes to the East River and the Kill van Kull, while the remainder goes to the Hudson River. When the flow through the Kill van Kull meets the flow through the Arthur Kill at Bergen Point, a tidal eddy is generated. The flow then continues north to the Upper Newark Bay.

In the Harbor, NOS maintains a PORTS for navigation safety. Information provided to the users by NY PORTS includes: water level at Sandy Hook, Kings Point, The Battery, and Bayonne Bridge; meteorological conditions at Robbins Reef, Bayonne Bridge, Sandy Hook, and Kings Point; and water currents at Bergen Point and The Narrows (Figure 2.1).

NOS's PORTS provides near real-time information to users only at the gage stations. However, there is still need for information in addition to the near real-time information at PORTS stations, including:

(1) near real-time water level and current information at non-gauge locations,
(2) short term (1 to 2 days) water level and current forecast guidance information, and
(3) detailed current information in navigational channels, such as the Kill van Kull, for Coast Guard "right of way" decision making.

Figure 2.2(a) shows a water level time series at the Bayonne Bridge from January 11 to 16, 2002. On January 13, due to a strong westerly wind (Figure 2.2(b)), the observed water levels (asterisks) dropped from 0.5 m above the astronomical tide prediction (solid line) to 0.8 m below the astronomical tide prediction within 24 hours. This situation poses a grounding risk. Therefore, for navigation safety, there is the need for a more accurate tool other than just the astronomical prediction. The Port of New York/New Jersey Experimental Water Level and Current Nowcast/Forecast Model System is designed for this purpose. Figure 2.2(c) shows the improvement that the model system water provided for the same period. Both the model nowcast (dotted line) and the forecast (dashed line) are much closer to the observations than just the astronomical tide predictions. This example shows that an oceanographic forecast system based on a hydrodynamic model is an effective tool to make near real-time nowcasts and short term forecasts of the water levels and currents in an estuary.

Marine pilots of the Port of New York and New Jersey maritime community such as the Sandy Hook Pilots Association have participated in activities of the Harbor Navigation on Committee organized by the Port Authority of New York & New Jersey. Through this Committee, representatives from NOS's Office of Coast Survey have collected the oceanographic information needs voiced by the marine pilots and other users. In May 2001, a user needs and requirements questionnaire was distributed to the maritime community for information. The questionnaire, designed by CSDL, requested users to identify their priorities for oceanographic parameters (water level, current, salinity, and temperature), the information on necessary locations and the information on frequency and error tolerance.

The results from returned questionnaires are summarized as follows:

(1) The oceanographic parameters of highest priority are water level and current nowcasts and forecasts.
(2) The locations of highest priority are shown in Figure 2.3. In response to the survey, NOS deployed a current meter at The Narrows in August, 2001 as part of the NY PORTS.
(3) The forecast information should be at least out to 24 hours.
(4) The forecast information report frequency should be at least hourly or shorter.
(5) The forecast information should be updated at least four times a day.
(6) The nowcast and forecast error tolerance proposed by NOS (1999) for water level and current speed are acceptable (e.g., 90% of the time the errors be less than 0.5 ft for water level and 0.5 kt for current speed).
(7) A 95% confidence limit is recommended.
(8) Dissemination methods requested include web-based time series plots, plan views, and PORTS screen display.

All of this information will be used to improve and modify the model system design before it becomes operational.

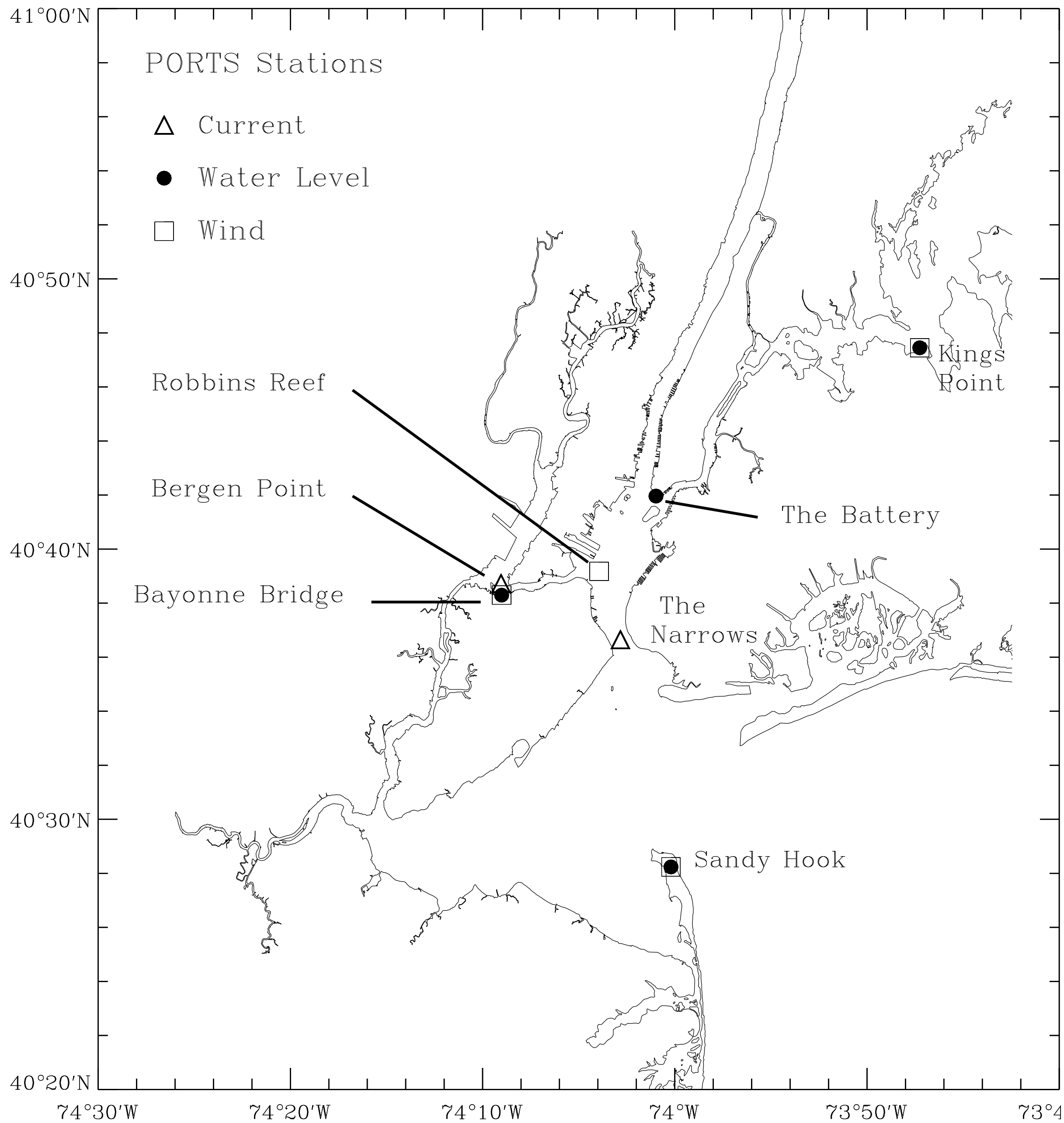


Figure 2.1. New York Harbor PORTS stations maintained by NOS.

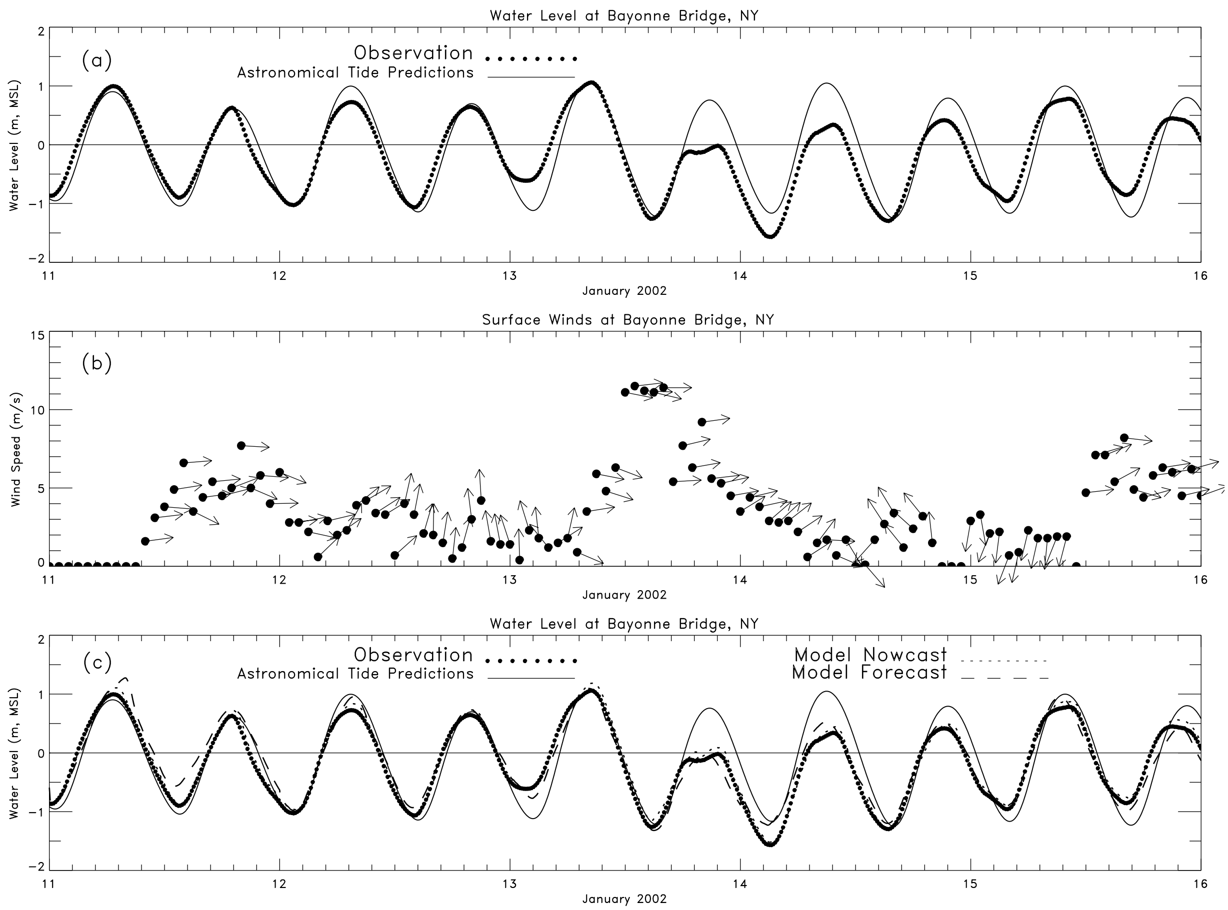


Figure 2.2. Water level at Bayonne Bridge; (a) observations and astronomical tide prediction, (b) surface wind observations, and (c) observations and astronomical tide prediction overlaid with model water level nowcast and forecasts.

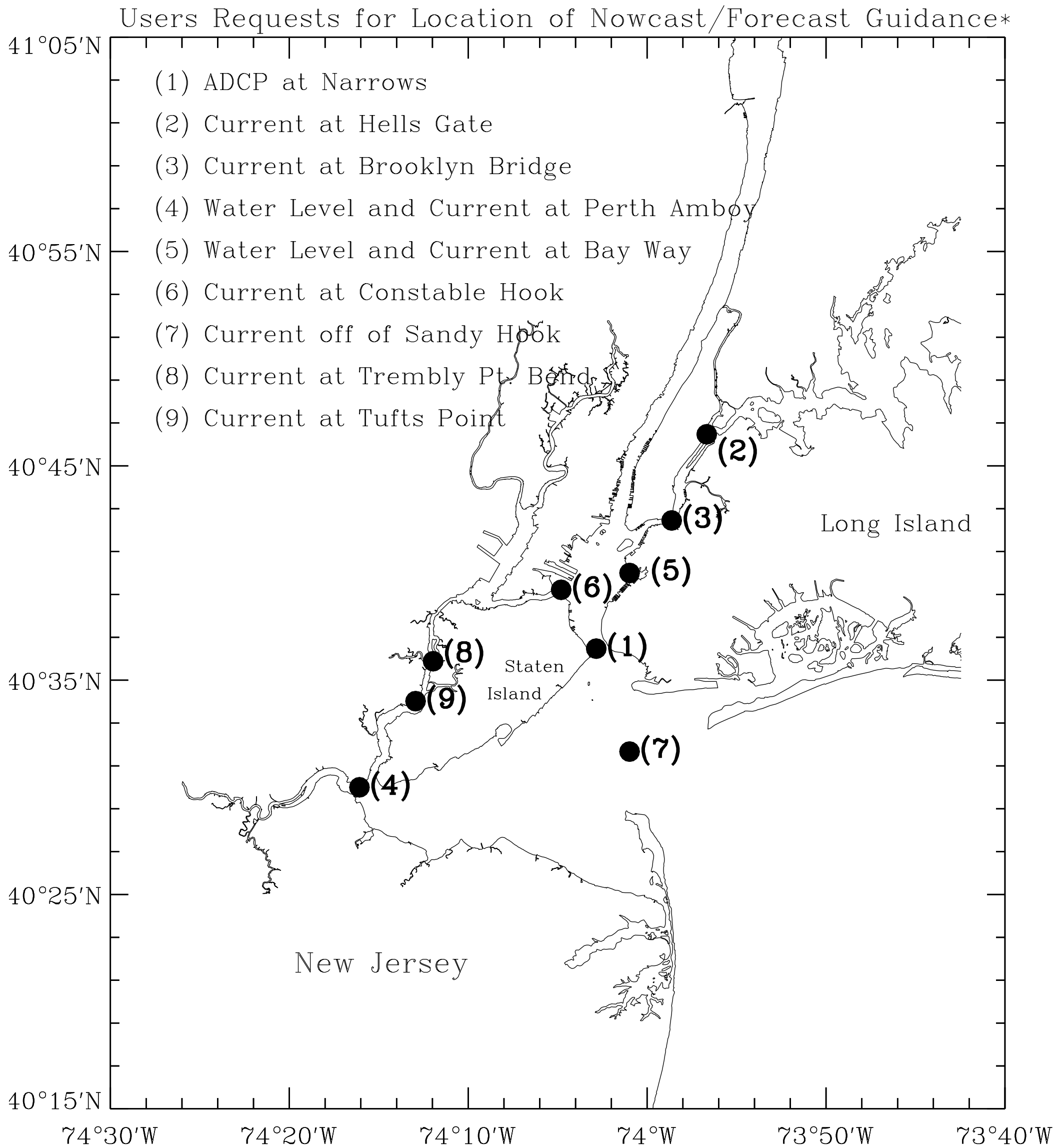


Figure 2.3. Parameters and locations that marine pilots request for navigation.

3. SYSTEM OVERVIEW

The NYEFS provides near real-time water level and current nowcasts and forecasts using a hydrodynamic model forced with water levels at the open ocean boundary and with winds on the water surface. The hydrodynamic model used for the system, as described in detail in Wei and Chen (2001), is a three-dimensional barotropic model based on the Princeton Ocean Model (POM, Blumberg and Mellor, 1987). The model requires forcing of real-time water levels and winds acquired from NOS's PORTS, sub-tidal water level forecasts acquired from the Extra-Tropical Storm Surge (ETSS) model (Chen et al., 1993; Kim et al., 1996), and wind forecasts acquired from the Eta (Black, 1994) model. The model grid information including bathymetry data is stored as a separate file. Data acquired are then formatted to be read directly by the model. With the near real-time input data and the initial conditions created by the previous nowcast, the hourly nowcast is executed to obtain the water levels and currents throughout the entire model grid for the past hour. The nowcast model fields at 05Z and 17Z are used for the 36 hour forecast run forced with Eta wind and ETSS water level forecasts. The forecast cycles will be extended from twice to four time a day (adding 11Z and 23Z cycles). Monthly climatological river discharges for the Raritan, Passic, Hackensack, and Hudson Rivers (Figure 1), generated from U.S. Geological Survey (USGS) observations, are used as fresh water input to the model. The output from the nowcast and forecast runs are processed and plotted with a graphic application for posting on the Internet. The NYEFS is implemented by various Unix scripts. Each script performs different operations including data gathering and quality control, executing nowcast and forecast simulations, and output data processes for product dissemination and graphic preparation. A schematic of the NYEFS system is shown in Figure 3.1 and also described in the following sections.

3.1. Data Ingestion and Boundary Forcing Generation

The data required for driving the model nowcast and forecast include the water levels as lateral open boundary conditions and winds as the surface forcing. For nowcast runs, near real-time water levels and winds at National Water Level Observation Network (NWLON) stations (Figure 2.1); Sandy Hook, NJ and Kings Point, NY (switching from Willets Points, NY on November 14, 2000) are available in PORTS Uniform Flat File Format (PUFFF) (Evans, et al., 1998) format for anonymous ftp (File Transfer Protocol) through Internet from the NYPORTS database server in NOS's Center for Operational Oceanographic Products and Services (CO-OPS). The near real-time water levels are acquired every 6 minutes and are processed hourly before each nowcast run. The non-tidal water levels are obtained by subtracting the astronomical tide prediction from the observations. In the case of data interruption, such as connection failure or erroneous data values, the non-tidal water levels are persisted and added to the tide predictions as a substitute for open boundary conditions at Sandy Hook and Kings Point. Therefore, the hourly nowcast run can be continued without interruption. Except when a strong wind prevails for a long duration, the water levels within the harbor are predominately determined by the water levels at the lateral open boundary at Sandy Hook. Therefore, in the case of data interruption, the nowcast can adequately run without any wind forcing.

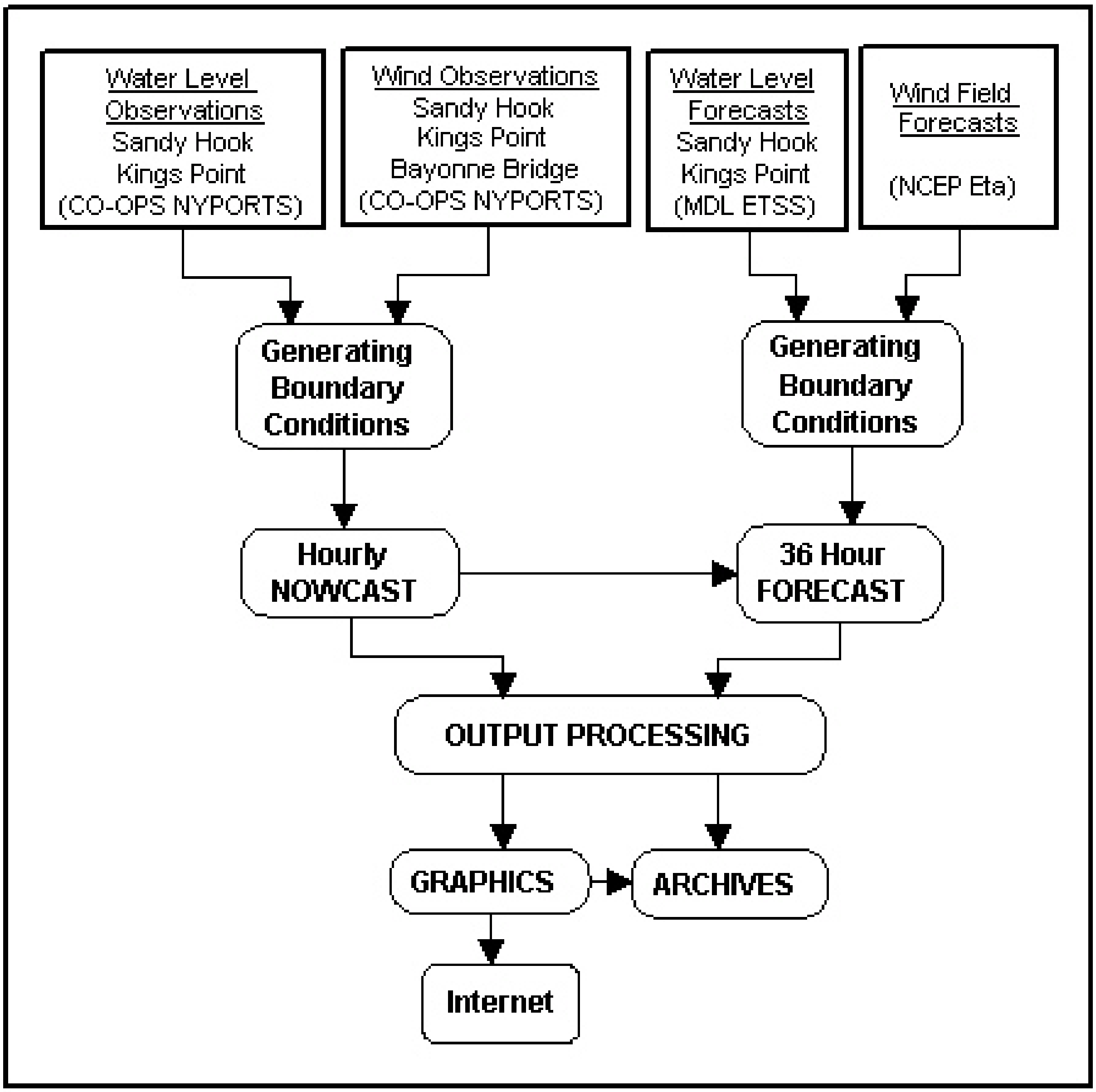


Figure 3.1. Schematic of the NYEFS operation function element.

Winds at the Bayonne Bridge are also obtained for model input. Water levels at the Bayonne Bridge and The Battery, and current velocity at The Narrows (starting July, 2001) are acquired for model verification purposes.

For the forecast, the wind-driven water level forecasts produced by NWS's Meteorological Development Laboratory (MDL) ETSS are acquired by NOS's Operational Data Acquisition and Archive System (ODAAS, Kelley et al., 2001) as the lateral open boundary condition. Since ETSS water level forecasts have a consistent datum bias, a correction procedure has been applied to reduce the errors. The correction procedure includes two steps. First, the averaged discrepancy between the previous 24 hour forecasts and observations at the NYEFS model open boundaries: Sandy Hook, NJ and Kings Pt., NY, are calculated. The next 24 hour forecast is corrected by the averaged datum discrepancy. Even after the datum bias correction, there is a water level gap between the last observed and the first forecast water level. To prevent any model instability from occurring, the first 6 hour datum-corrected ETSS forecasts are smoothed. The smoothed water level forecasts are then added to the astronomical tide predictions at Sandy Hook, NJ, and Kings Point, NY, for the model lateral open boundary conditions. Wind velocity forecasts acquired by ODAAS from the Eta model are used for surface forcing. Water level and wind data ingested for nowcast and forecast model runs are also archived for further evaluation.

3.2. Nowcast Run

The water level and wind boundary forcing fields at Sandy Hook and Kings Point are used to drive the hourly nowcast run. The model is initialized with the fully developed state saved from the previous nowcast run. The beginning hour is determined by the restart initial file. This hourly nowcast run produces the water levels and three-dimensional currents for the entire model grid. A restart file describing the entire mode grid ocean condition is created for the next hourly nowcast run, or for the forecast run. Water levels and currents at selected locations are processed for plotting the time series. Water levels and currents throughout the model domain are processed for the contour and current vectors plots, and displayed on the World Wide Web site. Nowcast data, such as water levels at model interior NWLON locations Bayonne Bridge and The Battery, and currents at Bergen Point, Bayonne Bridge, and The Narrows (Figure 2.1), are archived for model skill assessment. Water levels at additional locations (Figure 3.2), where no operational observations are available, are output for time series plotting.

3.3. Forecast Run

The twice a day forecast runs start when the forecast forcing input files, as described in Section 3.1, are generated. The monthly climatological river discharges that are used in the nowcast are used for the forecast. The model forecast is initialized with the fully developed state of motion field of the model nowcast. The model runs for the 36 hour forecast and the output is similar to the nowcast, i.e., water level and current throughout the entire domain and at selected locations, are processed and plotted. Model forecasts are archived for the skill assessment.

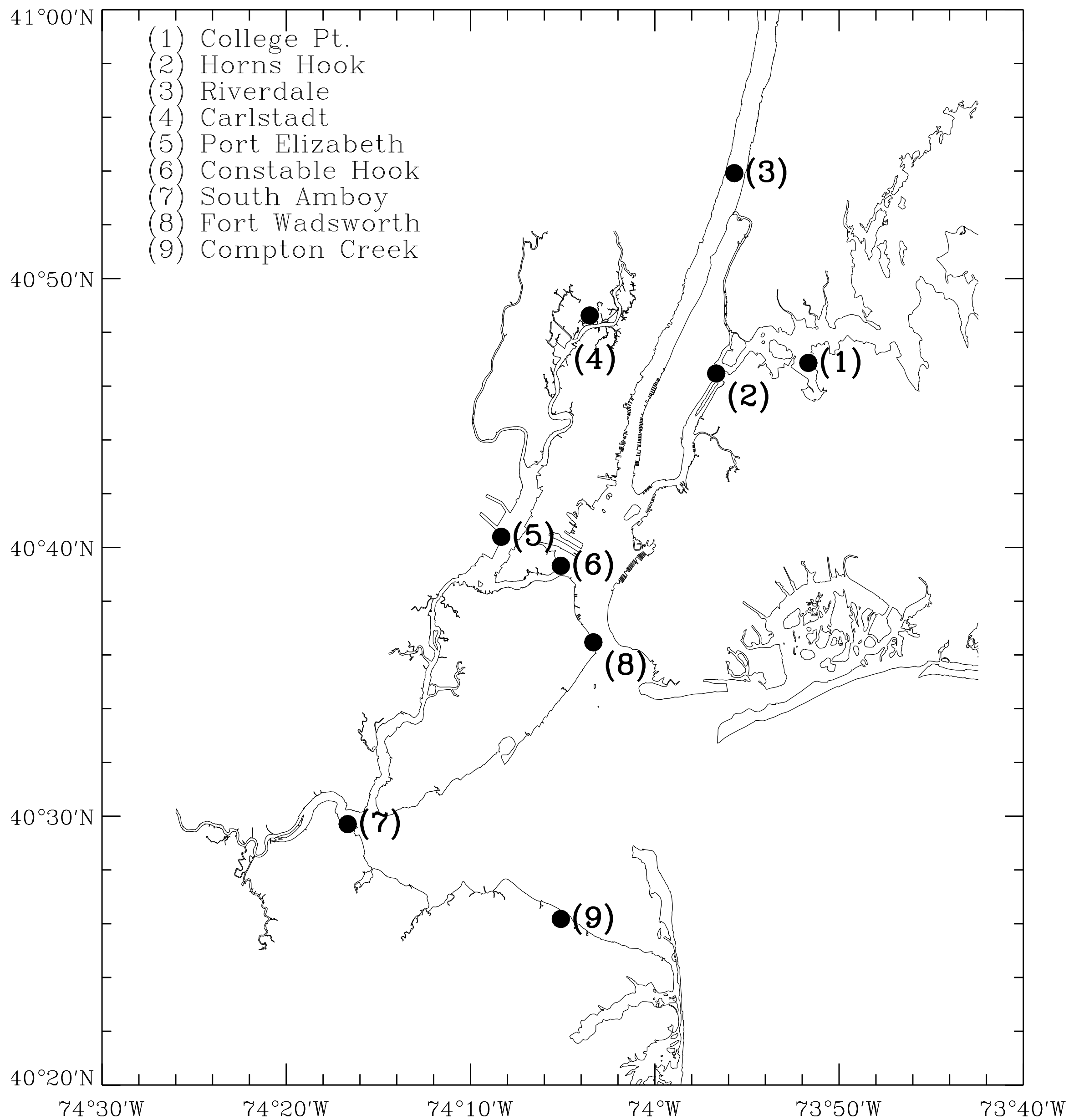


Figure 3.2. Station locations available for model system water level output.

3.4. Operational Environment and Scheduling

The NYEFS is running on two Silicon Graphics, Inc.(SGI) work stations at CSDL. The data ingestion, model nowcast and forecast, and output post-processing are running on an SGI Origin 2000 computer. This server is a high-end MIPS computer equipped with eight 400 MHz IP27 processors and 2 GB total memory and is using the IRIX 6.5 operating system. The IDL graphic software (Version 5.3) is used for generating water level and current time series, contour, and vector plots in gif or post-script format. The graphic server is an SGI Indigo2 computer equipped with a 195 MHz processor and 128 MB of memory; this server is also using the IRIX 6.5 operating system.

The NYEFS nowcast schedule is shown in Figure 3.3. NYEFS performs the data ingestion every 6 minutes to acquire PUFFF data and process the hourly data at minute 7 of each hour. The hourly model nowcast run is submitted at minute 8 of each hour (or after input data process is completed). The nowcast output process is followed immediately after the nowcast completion. The 05Z and 17Z forecast runs are submitted at 0520Z and 1720Z, respectively, for a 36-hour simulation. Shown in Figure 3.4, the forecast run starts with an initial condition defined by the corresponding hourly nowcast model field. Under a machine dedicated situation (i.e., no CPU competition), the hourly nowcast requires about 67 seconds in CPU time and the 36-hour forecast requires about 33 minutes CPU time.

3.5. System Interruption and Recovery Procedure

The NYEFS is implemented with UNIX scripts to control operational procedures. The run schedule of these scripts is controlled by UNIX crontab. These scripts have been frequently modified and updated since the system commenced in 1999. For example, a procedure has been adopted to accommodate the real-time water level interruptions at Sandy Hook and Kings Point. The procedure uses the “persistent sub-tidal water level” added to the astronomical tidal prediction to obtain the model open boundary forcing so that the nowcast run can continue without interruption. However, unexpected interruptions still occur. The interruptions result from many factors such as server shutdowns, network breakdowns, and NWLON station location changes (such as Willets Point to Kings Point). The forecast run can proceed without Eta wind forecasts, but it can not run without ETSS forecasts; a system interruption would occur if ETSS were not available from ODAAS.

A manual recovery procedure has been developed for the nowcast run; this procedure is also implemented with a UNIX shell script. This script is submitted manually by entering date information including the year, month, day, and hour when the last valid coarse grid and fine grid model restart files exist. The recovery script generates water level and wind forcing from PORTS archives based on the date information entered. The model will then run in a hindcast mode to bring the nowcast up to the “now” time. After the recovery hindcast is completed the system will operate normally.

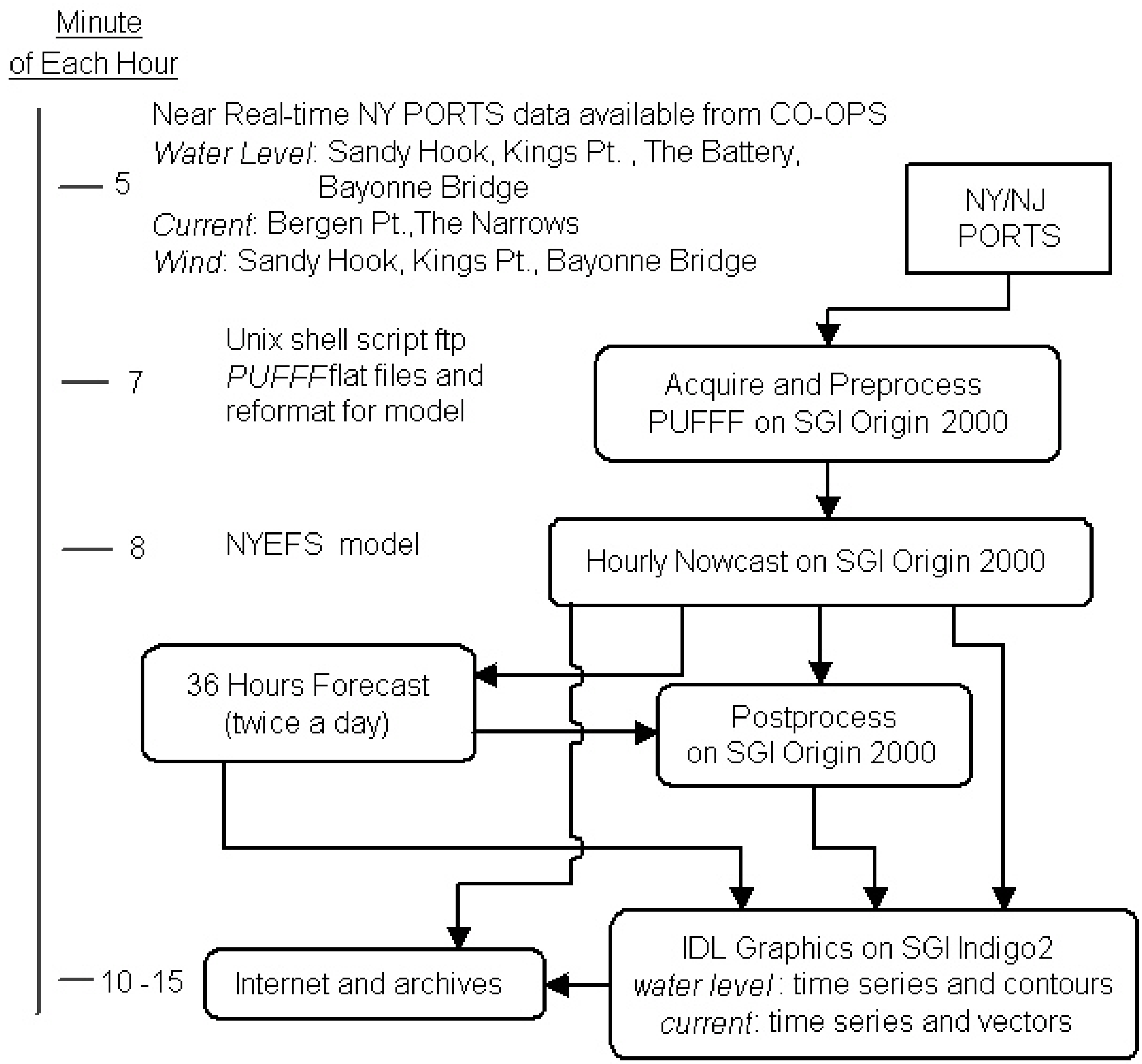


Figure 3.3. NYEFS nowcast run schedule.

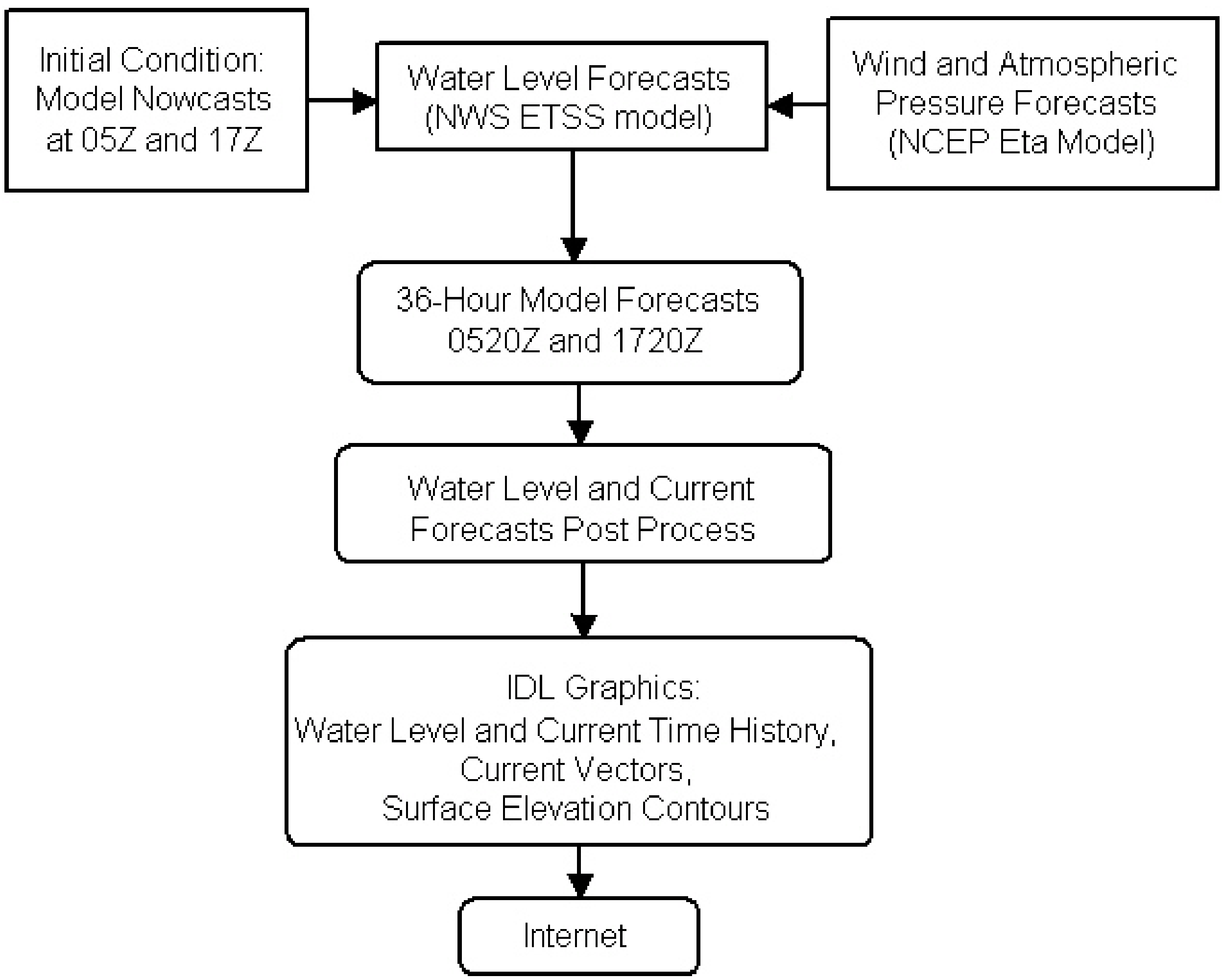


Figure 3.4. NYEFS forecast run schematic flow chart.

4. SEMI-OPERATIONAL NOWCAST/FORECAST SKILL ASSESSMENT

Skill assessments for tidal simulations and test nowcast assessments have been reported as part of the NYEFS model documentation in Wei and Chen (2001). This report describes the model system performance based on NOS requirements of an operational nowcast/forecast system (NOS, 1999). According to NOS (1999), the definition of model run scenarios for semi-operational nowcast/forecast are as follows:

Semi-operational Nowcast: In this scenario, the model is forced with actual observational input data streams including open ocean boundary water levels, wind stresses, river flows, and water density variations. Significant portions of the data may be missing, so the model must be able to handle this.

Semi-operational Forecast: In this scenario, the model is forced with actual forecast input data streams, including open ocean boundary water levels, wind, river flows, and water density variations. Initial conditions are generated by observed data. Significant portions of the data may be missing, so the model must be able to handle this.

The NYEFS, as described in Chapter 3, has been implemented on CSDL's SGI computers to produce hourly water level and current nowcasts and twice daily forecasts in New York Harbor. The water level model nowcasts and forecasts at NWLON stations; Bayonne Bridge and The Battery are archived for system skill evaluation. This chapter describes the analysis method, the skill parameters, and the evaluation results. Analysis (Wei and Chen, 2001) shows water level discrepancy from the fine grid and coarse are negligible but not current velocity. Therefore, if available, outputs from the fine grid model are used in the analysis described in this Chapter.

4.1. Analysis Method

A standard suit of assessment statistics is defined in NOS (1999). Parameters in the suite are calculated based on time series of observed and model-simulated water levels at the Bayonne Bridge and The Battery. Defining the error as the observations minus the semi-operational nowcasts, these parameters are (NOS, 1999):

(1) SM: Series mean.
(2) SD: Standard deviation of the error.
(3) RMSE: Root mean squared error.
(4) CF(x): Central Frequency. Percentage of errors that lie within the limit ±x
(5) POF(x): Positive Outlier Frequency. Percentage of errors that are greater than x.
(6) NOF(x): Negative Outlier Frequency. Percentage of errors that are less than x.
(7) MDPO(x): Maximum Duration of Positive Outliers. A positive outlier event is two or more consecutive occurrences of an error greater than x. MDPO is the length (number of consecutive occurrences) of the longest event.

(8) MDNO(x): Maximum Duration of Negative Outliers. A negative outlier event is two or more consecutive occurrences of an error less than -x. MDNO is the length (number of consecutive occurrences) of the longest event.
(9) WOF(X): Worst Case Outlier Frequency. Fraction (percentage) of errors that, given an error of magnitude exceeding X, that (1) the simulated value of water level is greater than the astronomical tide and the observed value is less than the astronomical tide or (2) the simulated value of water level is less than the astronomical tide and the observed value is greater than the astronomical tide.

4.2. Skill Assessment for Water Level Nowcasts

Hourly water level model nowcasts at the Bayonne Bridge and The Battery NWLON stations have been archived daily for model system evaluations since April 1, 1999. Only data associated with normal model system operation are selected. The skill assessment described in this chapter is based on the time series archived between April 1, 1999, and July 31, 2001. Model data from April to September 2000 were not saved and not included in the analysis. No observed water level data is available at the Bayonne Bridge station for March 2000 and at The Battery from January to May 2001. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. Included in the analysis are 11,996 and 9,884 hourly water level data values extracted from 6-minute model output at the Bayonne Bridge and The Battery, respectively. Figures 4.1 and 4.2 show a portion of the observed and model nowcast water level time series at the Bayonne Bridge and The Battery.

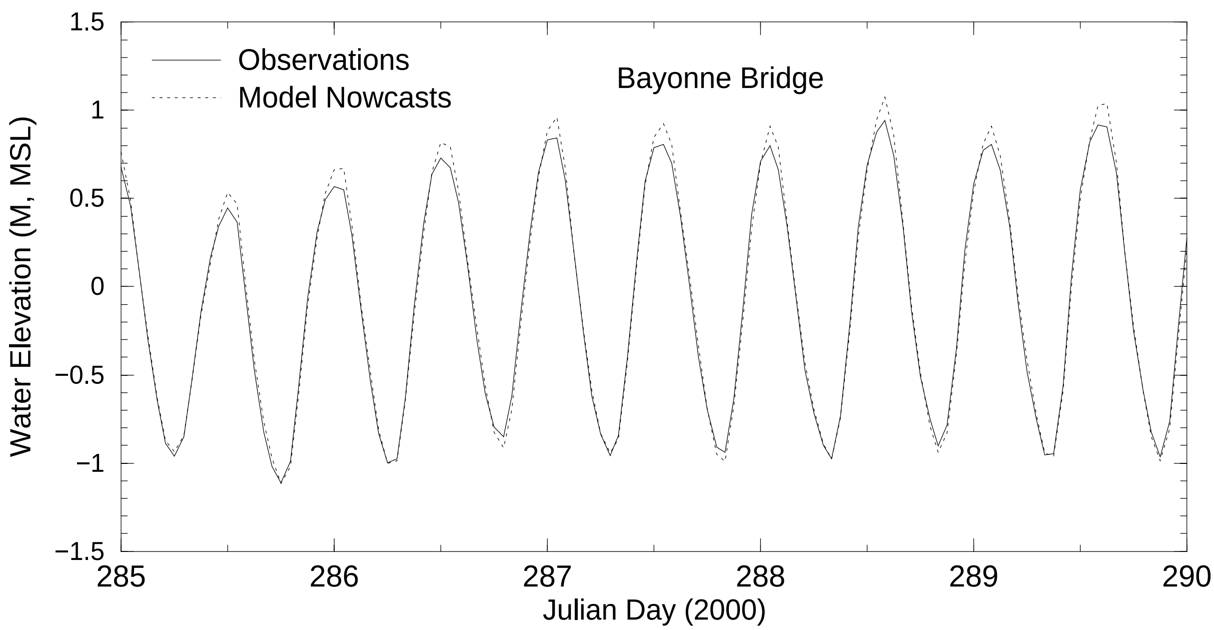


Figure 4.1. Observed and model nowcast water level time series at the Bayonne Bridge, October 12 - 17, 2000.

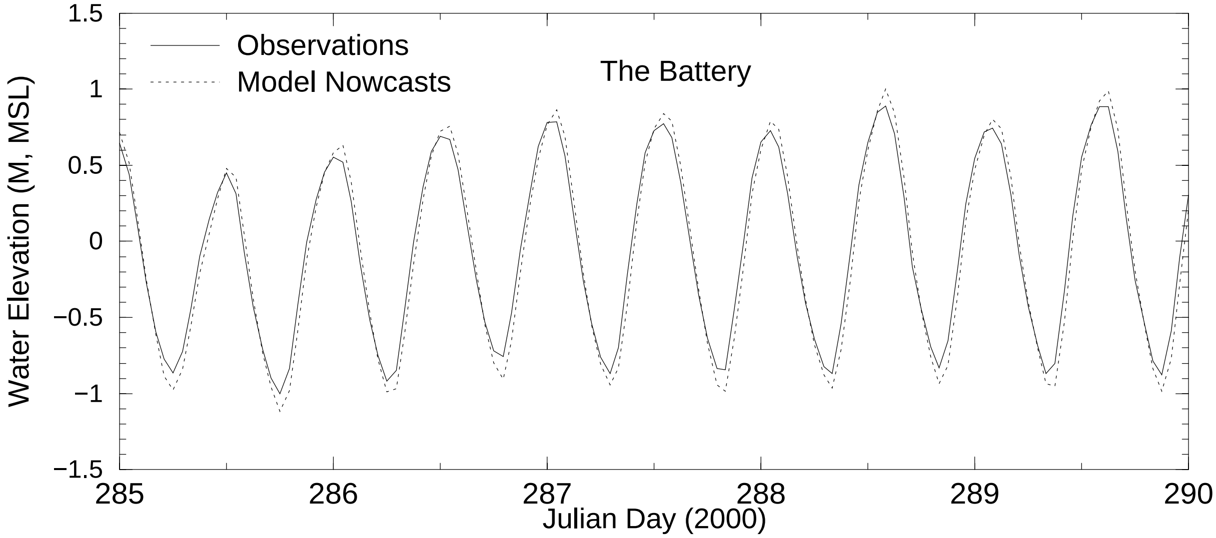


Figure 4.2. Observed and model nowcast water level time series at The Battery, October 12 - 17, 2000.

Water level semi-operational nowcast statistics at the Bayonne Bridge and The Battery are listed in Table 4.1. The criteria accepted by NOS are also included in the table. All model statistical parameters pass the criteria. The water level time series means (SM) between model simulated and observed data at both locations are very close indicating the model reference datum is correct. Time series difference root-mean-square errors (RMSE) are 7.3 cm at the Bayonne Bridge and 9.5 cm at The Battery.

A standard suite of assessment statistics for amplitudes and times of high and low water are computed for the Bayonne Bridge and The Battery. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. The high and low water time series subsets are derived from the entire 6-minute simulated and observed water level time series and the differences are computed.

The standard suite of statistical parameters are derived and listed in Tables 4.2 and 4.3. All statistical parameters at the Bayonne Bridge are within NOS accepted criteria. The simulated high and low waters lag behind the observations about 20 minutes at both locations. At both locations, the mean model high water amplitudes are higher than the observations and the mean model low water amplitudes are lower than the observations.

Table 4.1. Model system water level nowcast skill assessment standard statistics for complete time series at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Acceptance Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	5.9	6.5	0.6	6.5	7.1	0.5	na
SD (cm)	na	na	7.3	na	na	9.5	na
RMSE (cm)	na	na	7.3	na	na	9.5	na
CF (15 cm) %	97.4			92.4			≥90
POF (30 cm) %	0.2			0.2			≤ 1
NOF (30 cm) %	0.1			0.1			≤ 1
MDPO (30 cm) (Hour)	5			4			≤ 24
MDNO (30 cm) (Hour)	2			2			≤ 24
WOF (30 cm) %	0.1			0.1			≤ 0.5

Table 4.2. High and low water level nowcast skill assessment standard suite statistics at the Bayonne Bridge. (Note: na = not applicable)

	Bayonne Bridge				NOS Acceptance Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	4.6	15.1	-1.6	0.5	na
Difference SD (cm) (min)	6.7	15.4	4.6	12.6	na
RMSE (cm) (min)	8.1	21.6	4.9	12.6	na
CF (15 cm) (30 min) %	96.1	90.1	99.1	97.8	≥ 90
POF (30 cm) (60 min) %	0.3	0.7	0.3	0.2	≤1
NOF (30 cm) (60 min) %	0	0.3	0	0.4	≤1
MDPO (30 cm) (#)	2	1	2	1	≤ 3
MDNO (30 cm) (#)	0	1	0	1	≤ 3

Table 4.3. High and low water level nowcast skill assessment standard suite statistics at The Battery. (Note: na = not applicable)

	The Battery				NOS Accepted Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	8.9	14.8	-7.2	7.1	na
Difference SD (cm) (min)	4.1	12.3	4.3	11.5	na
RMSE (cm) (min)	9.8	19.2	8.4	13.5	na
CF (15 cm) (30 min) %	96.1	92.6	98.4	97.9	≥ 90
POF (30 cm) (60 min) %	0.3	0.4	0.3	0.3	≤1
NOF (30 cm) (60 min) %	0	0	0.1	0.1	≤1
MDPO (30 cm) (#)	2	1	2	1	≤ 3
MDNO (30 cm) (#)	0	0	1	1	≤ 3

4.3. Skill Assessment for Water Level Forecasts

The NYEFS makes 36-hour forecast runs twice a day. Each forecast run uses the datum-corrected ETSS subtidal water level forecasts, added to the astronomical tide predictions at Sandy Hook, NJ and Willets Pt. (Kings Point), NY as lateral open ocean boundary conditions. The other lateral open boundary condition is the climatological river flow described at river mouths. The model is forced with Eta forecasts on the surface. The forecast runs start the simulation at 05Z and 17Z and produce water level and three-dimensional current forecasts over 36 hours. Hourly water level data of the first 24 hours of the forecasts, at the Bayonne Bridge and The Battery, from October 2000 to July 2001, are used for the skill assessment. There are about 270 days (two forecast cycles each day) of valid model data. However, observed data at The Battery are not available between January1, and April 30, 2001. Figures 4.3 and 4.4 show the observed and model forecast water level time series at the Bayonne Bridge and The Battery.

Following NOS (1999), the statistic parameters including CF, POF, NOF, MDPO, MDNO and RMSE, at each forecast hour are calculated. The statistics from the 05z and 17z cycles are similar although the 05z cycle statistics are slightly better than 17z cycle in general. Tables 4.4 and 4.5 list these parameters at each forecast hour (hour 1, 6, 12, 18, and 24 are highlighted) using the two cycle model forecast data. The overall statistics are listed as Table 4.6.

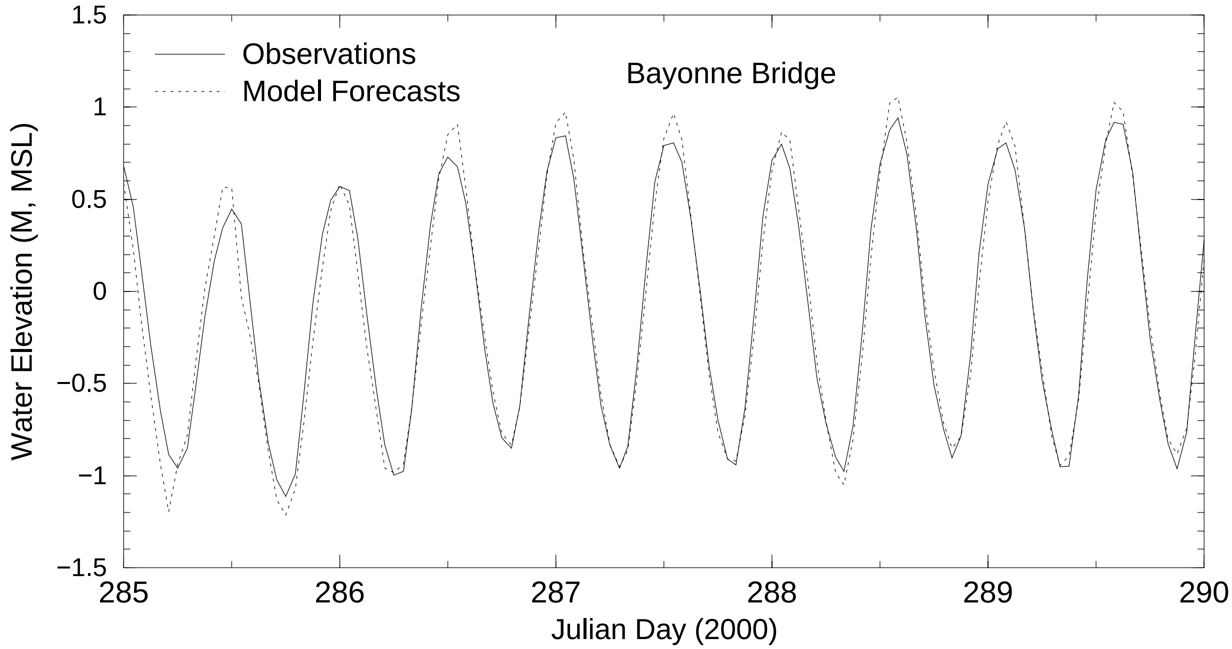


Figure 4.3. Observed and model forecast water level time series at the Bayonne Bridge, October 12 - 17, 2000.

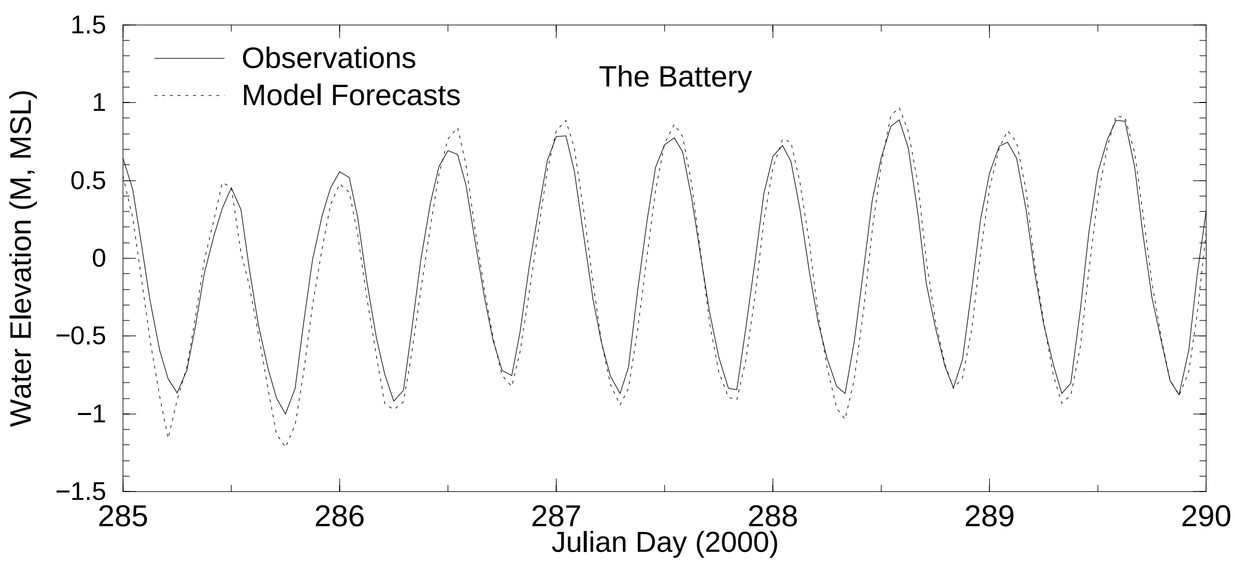


Figure 4.4. Observed and model forecast water level time series at The Battery, October 12 - 17, 2000.

Table 4.4. Model system water level forecast skill assessment standard statistics for complete time series (two cycle forecasts) at Bayonne Bridge. (Note: Overall RMSE average: 13.4 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	97.2	0.4	0.0	6.9
2	86.2	0.9	0.2	10.6
3	86.8	0.6	0.4	10.7
4	84.6	0.2	0.6	10.9
5	83.8	1.1	0.4	11.8
6	79.0	1.5	0.6	12.2
7	82.5	0.9	0.9	12.0
8	66.2	5.8	3.0	16.9
9	70.1	5.0	1.1	14.9
10	79.9	1.9	0.2	12.1
11	75.8	1.9	0.7	13.1
12	79.4	2.4	0.2	12.6
13	74.7	1.5	0.4	12.7
14	73.4	2.0	1.7	13.7
15	74.3	2.0	2.4	14.0
16	68.8	1.7	2.2	14.7
17	69.1	2.8	2.2	15.2
18	70.3	3.2	2.2	15.0
19	70.6	3.0	1.9	15.1
20	68.8	3.5	2.6	15.4
21	69.5	3.2	2.4	15.1
22	72.1	2.4	1.5	14.4
23	74.2	2.0	1.7	13.7
24	75.1	2.4	1.7	13.6

Table 4.5. Model system water level forecast skill assessment standard statistics for complete time series (two cycle forecasts) at The Battery. (Note: Overall RMSE average: 14.3 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	89.9	0.0	3.6	11.2
2	82.1	0.0	3.3	12.7
3	77.2	0.3	3.6	13.5
4	75.2	0.0	2.6	13.5
5	74.9	0.7	2.0	13.8
6	74.6	0.3	2.6	13.8
7	73.0	1.0	1.3	12.9
8	67.8	2.9	1.6	15.6
9	72.6	2.3	1.3	14.0
10	77.9	1.0	2.9	13.2
11	75.2	1.0	2.9	13.9
12	73.6	0.7	3.6	14.1
13	72.0	0.0	2.9	14.3
14	73.0	1.0	3.6	14.9
15	68.1	0.7	5.2	15.1
16	66.4	0.7	4.6	15.1
17	65.1	1.3	3.9	15.4
18	66.8	1.3	3.6	15.5
19	66.8	2.9	2.3	15.4
20	67.1	3.3	1.6	15.2
21	72.3	3.6	1.3	14.7
22	72.6	2.9	1.6	14.6
23	71.7	1.6	2.9	14.4
24	70.7	0.7	2.9	14.4

Table 4.6. Model system water level forecast skill assessment standard statistics at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Acceptance Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	5.1	6.7	1.6	6.5	7.5	-1.5	na
SD (cm)	na	na	13.3	na	na	14.2	na
RMSE (cm)	na	na	13.4	na	na	14.3	na
CF (15 cm) %	76.4			72.8			≥90
POF (30 cm) %	2.2			1.3			≤ 1
NOF (30 cm) %	1.3			2.8			≤ 1
MDPO (30 cm) (Hour)	10			6			≤ 24
MDNO (30 cm) (Hour)	8			7			≤ 24
WOF (30 cm) %	2.0			2.2			≤ 0.5

Since the water level forecasts at the Bayonne Bridge and The Battery heavily depend on the ETSS forecasts at Sandy Hook, NJ (the 00Z ETSS cycle described in Section 3.1), the accuracy of ETSS forecasts at Sandy Hook is crucial. Inter-comparisons of ETSS forecasts with observations at Sandy Hook show ETSS forecasts consistently underestimate the sub-tidal water levels shown in Tables 4.7. Table 4.7 shows the RMSE of ETSS forecasts is 21.6 cm. The central frequency (15 cm) ranges from 30% to 50% and the NOF (30 cm) are greater than 10% but there are zero POF. Several correction approaches have been tested, for example, corrected with the average of the discrepancy between the observations and forecasts of the previous one, five, seven, and ten days. Table 4.8 shows the statistics of ETSS forecasts after the correction procedure using the previous one-day average discrepancy approach. The RMSE has been reduced to 13.3 cm and the CF increased to greater than 90% out to forecast hour 6. The corrected RMSE using other methods are all greater than 13 cm. The water level boundary conditions for semi-operational forecast runs are based on the previous one day discrepancy correction.

The water level forecast errors at the Bayonne Bridge and The Battery are expected to be greater than that at Sandy Hook. Shown in Tables 4.5 and 4.6 the Central Frequency (CF) decreases to about 80% and 74% at forecast hour 6 at the Bayonne Bridge and The Battery, respectively. At the Bayonne Bridge, the POF is greater than 1% after forecast hour 4 while the NOF is less than 1% up to forecast hour 13, except at forecast hours 8 and 9. At The Battery, the NOF is much greater than the POF for all forecast hours and the RMSE (14.3 cm) is greater than at the Bayonne Bridge.

Table 4.7. ETSS water level forecast skill assessment standard statistics at Sandy Hook. (Note: Overall RMSE average: 21.6 cm.)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	30.0	0.0	16.6	25.0
2	27.9	0.0	19.1	25.5
3	31.4	0.0	15.5	24.9
4	42.8	0.4	12.4	22.1
5	49.8	0.0	10.2	20.2
6	51.2	0.0	8.1	18.9
7	49.5	0.0	9.5	19.8
8	46.3	0.0	9.9	20.2
9	39.9	0.0	13.1	21.4
10	38.5	0.0	13.8	21.7
11	42.8	0.0	11.3	20.8
12	49.8	0.0	9.2	20.4
13	55.5	0.0	9.2	21.3
14	53.4	0.0	11.0	21.5
15	54.1	0.0	11.7	21.7
16	51.9	0.0	10.6	22.1
17	53.0	0.0	13.4	21.8
18	51.9	0.0	13.8	21.4
19	49.1	0.0	14.5	21.2
20	48.8	0.0	12.7	21.6
21	50.2	0.0	14.5	20.9
22	49.8	0.0	15.2	20.3
23	50.9	0.0	15.2	20.8
24	44.9	0.0	18.7	23.5

Table 4.8. ETSS water level forecast skill assessment standard statistics at Sandy Hook *after the correction*. (Note: Overall RMSE average: 13.3 cm)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMSE (cm)
1	93.3	0.0	1.4	9.9
2	90.1	0.4	0.7	11.0
3	90.8	0.4	1.8	12.1
4	92.9	0.7	1.4	10.5
5	91.9	1.1	0.7	9.8
6	94.0	1.1	0.4	9.5
7	84.1	2.5	1.8	13.3
8	82.0	1.8	1.8	13.0
9	79.5	1.4	0.7	12.5
10	79.9	1.1	0.7	12.4
11	79.5	0.7	0.7	12.2
12	80.6	1.1	1.1	13.4
13	76.7	2.1	2.5	15.6
14	76.7	2.1	2.1	15.2
15	78.1	2.8	1.8	15.2
16	74.6	1.8	1.8	15.7
17	76.3	2.1	2.5	15.0
18	77.4	1.4	2.8	14.5
19	74.2	1.4	1.4	14.0
20	75.3	2.1	1.4	14.1
21	75.6	2.1	1.4	14.0
22	73.9	1.8	1.8	13.6
23	76.3	1.8	1.8	13.9
24	75.6	1.1	3.2	14.7

The NYEFS water level forecasts are then compared with astronomical tide predictions (based on the NOS harmonic constants) at the Bayonne Bridge and The Battery. Table 4.9 lists the skill assessment parameters for overall time series between forecasts/predictions and observations from October, 2000 to July, 2001.

At the Bayonne Bridge, the model water level forecast skills do not meet the NOS accepted criteria; however, they are still better than the astronomical tide prediction in which the MDPO and MDNO are greater than 24 hours. At The Battery, the NYEFS forecasts only show slight accuracy improvement over astronomical tide predictions. The astronomical tide predictions at The Battery have a 48 hour MDNO and a negative difference series mean (SM) indicating a strong subtidal signals during this period.

Table 4.9. NYEFS water level forecast and astronomical tide prediction skill assessment standard suite statistics at the Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge		The Battery		NOS Acceptance Criteria
	NYEFS	Tide Predictions	NYEFS	Tide Predictions	
Difference SM (cm)	1.8	-6.0	-1.5	-7.9	na
Difference SD (cm)	13.3	17.3	14.2	14.4	na
RMSE (cm)	13.4	18.3	14.3	16.4	na
CF (15 cm) %	76.4	65.6	72.8	71.0	≥ 90
POF (30 cm) %	2.2	3.1	1.3	1.2	≤1
NOF (30 cm) %	1.3	5.7	2.8	5.8	≤1
MDPO (30 cm) (#)	10	26	6	7	≤ 24
MDNO (30 cm) (#)	8	47	7	48	≤ 24

A standard suite of assessment statistics for forecast water level amplitudes and times of high and low water are computed for the Bayonne Bridge and The Battery. Simulated water levels at the Bayonne Bridge and The Battery are taken from the fine grid and coarse grid, respectively. The high and low water time series subsets are derived from the entire 6-minute simulated and observed water level time series and the differences are computed. The standard suite of statistical parameters are derived and listed in Tables 4.10 and 4.11.

Similar to the entire forecast time series skill statistics, most of the forecast high and low water skill statistics for the Bayonne Bridge and The Battery do not meet the NOS criteria (NOS, 1999). The amplitude statistics CF at both locations are low compared with the time occurrence statistics CF. The results are not surprising given the inaccurate water level forecasts at Sandy Hook.

Table 4.10. High and low water level forecast skill assessment standard suite statistics at the Bayonne Bridge. (Note: na = not applicable)

	Bayonne Bridge				NOS Acceptance Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	10.4	7.3	-0.4	-5.8	na

Difference SD (cm) (min)	11.0	21.6	10.8	20.9	na
RMSE (cm) (min)	15.1	22.8	10.8	21.7	na
CF (15 cm) (30 min) %	70.2	85.3	85.8	88.4	≥ 90
POF (30 cm) (60 min) %	5.0	1.6	0.6	1.2	≤1
NOF (30 cm) (60 min) %	0	0	0.8	1.2	≤1
MDPO (30 cm) (#)	2	1	1	1	≤ 24
MDNO (30 cm) (#)	0	0	1	1	≤ 24

Table 4.11. High and low water level forecast skill assessment standard suite statistics at The Battery. (Note: na = not applicable)

	The Battery				NOS Acceptance Criteria
	High Water		Low Water		
	Amplitude	Time	Amplitude	Time	
Difference SM (cm) (min)	6.6	9.9	-8.7	-0.3	na
Difference SD (cm) (min)	10.8	21.2	11.8	20.6	na
RMSE (cm) (min)	12.7	23.4	14.6	20.6	na
CF (15 cm) (30 min) %	77.5	87.8	73.4	92.1	≥ 90
POF (30 cm) (60 min) %	2.3	2	0	0.7	≤1
NOF (30 cm) (60 min) %	0	0.3	5.3	0.7	≤1
MDPO (30 cm) (#)	2	1	0	1	≤ 24
MDNO (30 cm) (#)	0	1	3	1	≤ 24

4.4. Skill Assessment for Persisted Water Level Forecasts

A forecast method which provide timely information without running a hydrodynamic modeling is the so called persisted water level forecasts. In this method, the last available observed water level offset from the astronomical tide at a location is added to the future astronomical tide predictions to obtain the water level foreca1sts. This section describes the persisted water level forecasts skill assessments at The Battery and the Bayonne Bridge during the same period (October 1, 2000 - July 31, 2001) of the model forecast skill assessments described in Section 4.3.

The observed water level offset from the astronomical tide predictions at The Battery and the Bayonne Bridge at 05Z and 17Z were used to added to the followed 24 hours astronomical tide predictions as persisted water level forecasts. The persisted water level forecasts are then compared with observations to obtain the skill assessments as listed in Table 4.12. Comparing the skill assessments for the persisted water level forecasts (Table 4.12), the model water level forecast (Table 4.6), and the astronomical tide predictions (Table 4.9) shows that the CF, POF, and NOF for the persisted water level forecasts, especially at The Battery, are better that the other methods. However, the model's MDPO and MDNO are lower than the other methods.

The skill assessments at each forecast hour are listed in Tables 13 and 14. At the Bayonne Bridge, the skill for the persisted water level forecasts (Table 13) decreases with time and better than the model skills (Table 4.4) up to about 14 hours. However, the overall RMSE is worse than the model. At The Battery, the persisted water level forecast skill (Table 14) is also decrease with the time, however, the CF is better than the model skills (Table 4.5) for all forecast hour, although not the POF and NOF. The persisted water level forecast analysis at Sandy Hook, the model water level open ocean boundary condition, reveals that the persisted water level forecast skills (Tables 15 and 16) are better than the datum adjusted ETSS forecast (Table 4.8). This may explain the skills at The Battery is also better than the model because of the direct coastal signal propagation from the Harbor entrance to The Battery.

Table 4.12. Persisted water level forecast skill assessment standard statistics at Bayonne Bridge and The Battery. (Note: na = not applicable)

	Bayonne Bridge			The Battery			NOS Acceptance Criteria
	Observed	Persisted	Difference	Observed	Persisted	Difference	
SM (cm)	5.1	-1.1	-0.9	9.0	2.2	-0.6	na
SD (cm)	na	na	14.7	na	na	11.6	na
RMSE (cm)	na	na	14.8	na	na	11.6	na
CF (15 cm) %	78.9			87.0			≥90
POF (30 cm) %	2.9			1.4			≤ 1
NOF (30 cm) %	2.2			1.2			≤ 1
MDPO (30 cm) (Hour)	23			17			≤ 24
MDNO (30 cm) (Hour)	14			15			≤ 24
WOF (30 cm) %	2.7			1.3			≤ 0.5

Table 4.13. Persisted water level forecast skill assessment standard statistics for complete time series (two cycle forecasts) at Bayonne Bridge. (Note: Overall RMSE average: 14.8 cm)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMS (cm)
1	98.8848	0.0000	0.0000	5.4919
2	90.7063	0.5576	0.3717	9.2504
3	88.6617	1.1152	0.7435	10.4519
4	89.5911	1.1152	0.9294	10.6006
5	88.1041	0.7435	0.5576	10.5355
6	85.1301	1.1152	0.9294	11.1770
7	84.7584	1.3011	0.9294	11.4261
8	83.2714	1.6729	1.3011	11.8294
9	81.2268	1.6729	1.8587	12.8411
10	78.4387	2.6022	1.6729	13.9050
11	77.8810	3.1599	1.3011	14.7958
12	80.1115	3.7175	2.2305	15.5267
13	79.7398	3.9033	2.2305	15.5949
14	75.4647	3.1599	2.7881	15.6582
15	74.1636	2.7881	2.4164	15.3925
16	74.1636	3.3457	2.6022	15.8148
17	72.4907	4.0892	2.9740	16.7263
18	69.7026	4.6468	3.3457	17.6887
19	68.5874	4.8327	3.5316	18.1382
20	69.7026	5.2045	3.9033	18.2320
21	71.5613	4.4610	3.7175	18.0261
22	70.2602	4.4610	4.2751	17.8864
23	70.4461	4.8327	4.4610	18.2202
24	70.0743	5.3903	4.6468	18.7142

Table 4.14. Persisted water level forecast skill assessment standard statistics for complete time series (tow cycle forecasts) at The Battery. (Note: Overall RMSE average: 11.6 cm)

Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMS (cm)
1	99.3485	0.0000	0.0000	4.8959
2	97.0684	0.0000	0.3257	7.7402
3	93.4853	0.0000	0.6515	8.8985
4	95.7655	0.9772	0.3257	8.9071
5	92.1824	0.6515	0.3257	9.2388
6	91.2052	0.6515	0.9772	9.5763
7	92.5081	0.3257	0.6515	8.9703
8	89.5765	0.9772	0.6515	9.0157
9	90.5537	0.9772	0.6515	9.8093
10	86.6450	1.3029	1.6287	10.8842
11	86.3192	1.9544	0.9772	11.5479
12	87.6221	1.9544	1.3029	11.5056
13	86.3192	1.3029	0.9772	11.7579
14	82.4104	1.6287	1.6287	11.9290
15	82.4104	1.9544	0.9772	12.1393
16	82.7362	2.2801	0.9772	12.9054
17	82.4104	2.6059	1.9544	13.8267
18	80.4560	1.6287	1.9544	14.2366
19	82.0847	2.6059	1.9544	13.9988
20	81.4332	2.6059	2.2801	13.6566
21	82.4104	2.2801	2.2801	13.5486
22	81.7590	1.9544	1.9544	13.5570
23	79.8046	1.9544	2.2801	14.2420
24	81.4332	1.9544	1.6287	14.4796

Table 4.15. Persisted water level forecast skill assessment standard statistics at Sandy Hook. (Note: na = not applicable)

	Sandy Hook			NOS Acceptance Criteria
	Observed	Persisted	Difference	
SM (cm)	8.3	-1.1	-0.3	na
SD (cm)	na	na	14.1	na
RMSE (cm)	na	na	14.1	na
CF (15 cm) %	80.9			≥90
POF (30 cm) %	2.5			≤ 1
NOF (30 cm) %	1.8			≤ 1
MDPO (30 cm) (Hour)	22			≤ 24
MDNO (30 cm) (Hour)	13			≤ 24
WOF (30 cm) %	2.2			≤ 0.5

Table 4.16. Persisted water level forecast skill assessment standard statistics at Sandy Hook. (Note: Overall RMSE average: 14.1 cm)

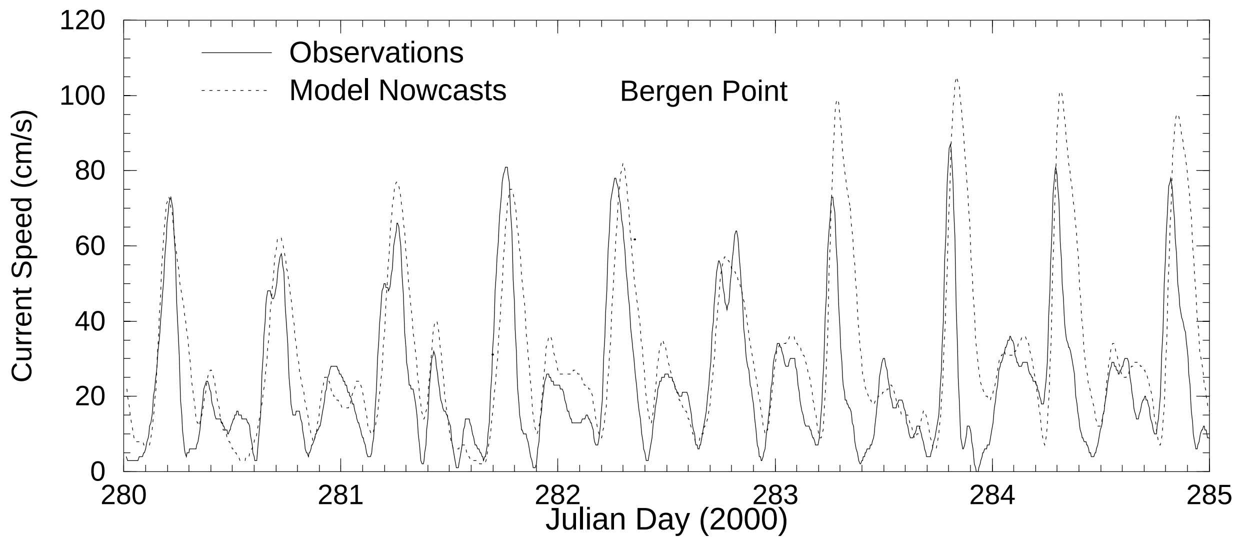
Forecast Hour	CF (15 cm)	POF (30 cm)	NOF (30 cm)	RMS (cm)
1	98.9399	0.0000	0.0000	4.8215
2	94.6996	0.0000	0.7067	8.0054
3	90.8127	0.3534	1.4134	9.7436
4	89.3993	1.0601	1.4134	10.3756
5	87.9859	2.1201	1.0601	11.0950
6	87.6325	2.1201	0.3534	11.1180
7	89.0459	2.1201	0.3534	10.8149
8	89.3993	1.7668	0.0000	10.4698
9	86.9258	1.4134	1.0601	10.9101
10	81.9788	1.4134	1.0601	11.8920
11	80.9187	1.7668	0.7067	12.4968
12	81.6254	2.8269	0.7067	13.1072
13	80.9187	2.1201	2.1201	13.9308
14	80.5654	2.1201	2.4735	14.3797
15	78.7986	2.4735	2.1201	14.8872
16	74.9117	3.1802	2.1201	15.2494
17	71.0247	3.1802	3.8869	16.1934
18	72.0848	3.5336	3.8869	16.8763
19	71.3781	4.2403	3.1802	17.4578
20	71.3781	3.8869	2.8269	17.8357
21	72.0848	3.8869	2.4735	17.9219
22	69.6113	4.2403	3.1802	18.0699
23	69.2579	4.9470	3.1802	19.0871
24	71.3781	4.9470	3.8869	19.1574

4.5. Skill Assessment for Current Nowcasts

Nowcast Current Speed and Direction Skill Assessment at Bergen Point

Current observations about 4 m below the water surface (bin 8) are compared with simulated fine-grid model current speed and direction nowcasts at equivalent depth (fine-grid model layer 3) at Bergen Point from October 6 to December 3, 2000. The observations are low-pass filtered with a 90-minute filter to remove high frequency disturbances. Selection of both the observed and modeled co-existing data results in over12,000 valid 6-minute samples, equivalent to about 51 days. The time difference (2 minutes) between simulated and observed data time has been neglected in calculating the statistics. The current speed time series between October 6 to 11, 2000 are shown in Figure 4.5. The maximum flood current speeds are much stronger than the maximum ebb current speeds. The parameters in the analysis are obtained based on the entire data set except for MDPO and MDNO, which are based on each continuous data segment.

Figure 4.5. Observed (low-passed) and model nowcast current speed time series at Bergen Point,



October 6 - 11, 2000.

Current speed and direction skill assessments for Bergen Point are listed in Table 4.17. The current speed CF (76.2%) is below the NOS acceptable criterion (90%). Current direction statistics (CF: 85.6%, POF: 0.7%, and NOF:0.6%) are better than the speed but CD is till below the accepted criterion. The speed RMS error of about 27 cm s^{-1} is mostly due to the phase lag of the simulated current speed. This can also be seen in the slack before flood (SBF) and slack before ebb (SBE) analysis results presented in Table 4.18.

Table 4.17. Nowcast current speed and direction skill assessment standard suite statistics at Bergen Point, based on 12,384 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Acceptance Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	28.3	44.7	16.3	228.7	232.3	3.5	na
SD (cm/s) (deg)	na	na	21.9	na	na	17.1	na
RMSE (cm/s) (deg)	na	na	27.0	na	na	17.5	na
CF (26 cm/s) (22.5 deg)%	76.2			85.6			≥ 90
POF (52 cm/s)(45 deg) %	8.5			0.7			≤1
NOF (52 cm/s) (45 deg)%	0			0.6			≤1
MDPO (52 cm/s) (45 deg)(Hour)	2.3			0.9			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			0.9			≤ 24

Nowcast Current Slack Time at Bergen Point

The beginning/end time of SBE and SBF are defined as at the time when current speed is less/greater 0.26 m s^{-1}. The skill assessment for the beginning and end time of SBE and SBF series at Bergen Point are computed. The observed and model simulated current nowcasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segments and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between the observed and the model-based nowcast currents. Table 4.18 lists the statistical parameters for Bergen Point. The model performance does not meet NOS standards due to the complex flow pattern and horizontal current shears near Bergen Point. When the criteria were relaxed (time limit was doubled), the skills of CF, POF, and NOF are improved, although they are still below the NOS criteria (Table 4.18).

Nowcast Maximum Flood and Ebb Currents at Bergen Point

Although these are not required by NOS (1999), the simulated time, speed, and direction of maximum flood and ebb currents at Bergen Point are compared with the observations to evaluate the model system performance. Table 4.19 shows the skill statistics in terms of CF, RSME, POF, and NOF.

It appears that RMSE for the speed and direction of maximum current is very low indicating the model performs well in defining the maximum current speeds and directions. However, the simulated time of maximum flood current lags behind the observations by 40 minutes (RMSE) (Figure 4.5).

Table 4.18. Skill assessment standard suite statistics for begin and end times of SBE and SBF differences between current observations (bin 8) and nowcasts (layer 3) at Bergen Point. Statistics below the double line represent the time limit criteria was doubled. (Note: na = not applicable)

	Bergen Point		NOS Acceptance Criteria
	SBE	SBF	
SM (minutes)	29.0	37.5	na
SD (minutes)	63.0	35.3	na
RMSE (minutes)	69.0	51.5	na
CF (15 minutes) %	10.9	25.3	≥ 90
POF (30 minutes) %	50.6	45.4	≤1
NOF (30 minutes) %	16.0	0.7	≤1
MDPO (30 minutes)	4	7	≤3
MDNO (30 minutes)	1	1	≤3
CF (30 minutes) %	33.3	53.9	
POF (60 minutes) %	37.2	22.7	
NOF (60 minutes) %	4.5	0	

Table 4.19. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (bin 8 of the current meter) and nowcast currents (in model layer 3) at Bergen Point. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	34.8	23.3	10.7	9.3	9.5	-2.0
SD (min) (cm/s) (deg)	24.1	13.0	3.2	52.0	7.8	14.9
RMSE (min) (cm/s) (deg)	42.3	26.7	11.1	52.5	12.2	15.0
CF (30 min) (26 cm/s) (22.5 deg)%	44.4	64.7	99.0	47.5	99.0	85.9
POF (60 min) (52 cm/s)(45 deg) %	16.2	2.0	0.0	20.2	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	7.1	0.0	0.0

Nowcast Current Speed and Direction at The Narrows

In July 2001, NOS installed a bottom mounted ADCP at The Narrows as part of the New York PORTS. Since August 2001, the model system started archiving the nowcast and forecast currents from the coarse grid model at this location. Current observations about 6 m below water surface (bin 20) are compared with simulated current speed and direction nowcasts at the equivalent depth (model layer 2) from August 14 to November 19, 2001. Observations are low-pass filtered with a 90 minute filter to remove high frequency disturbances. Selection of both the observed and modeled co-existing data results in almost 19,000 valid 6-minute samples, equivalent to about 79 days. The difference (2 to 3 minutes) between simulated and observed data has been neglected in calculating the statistics. The current speed time series from August 20 to 22, 2001 are shown in Figure 4.6. The maximum flood and ebb current difference is less than that at Bergen Point (Figure 4.5). The parameters in the analysis are obtained based on the entire available data set except for MDPO and MDNO, which are based on each continuous data segment.

Current speed and direction skill assessments for The Narrows are listed in Table 4.20. The model simulated current speed and direction at The Narrows are more accurate than at Bergen Point because of simple geometry and bathymetry of the waterway. All parameters satisfy NOS criterion.

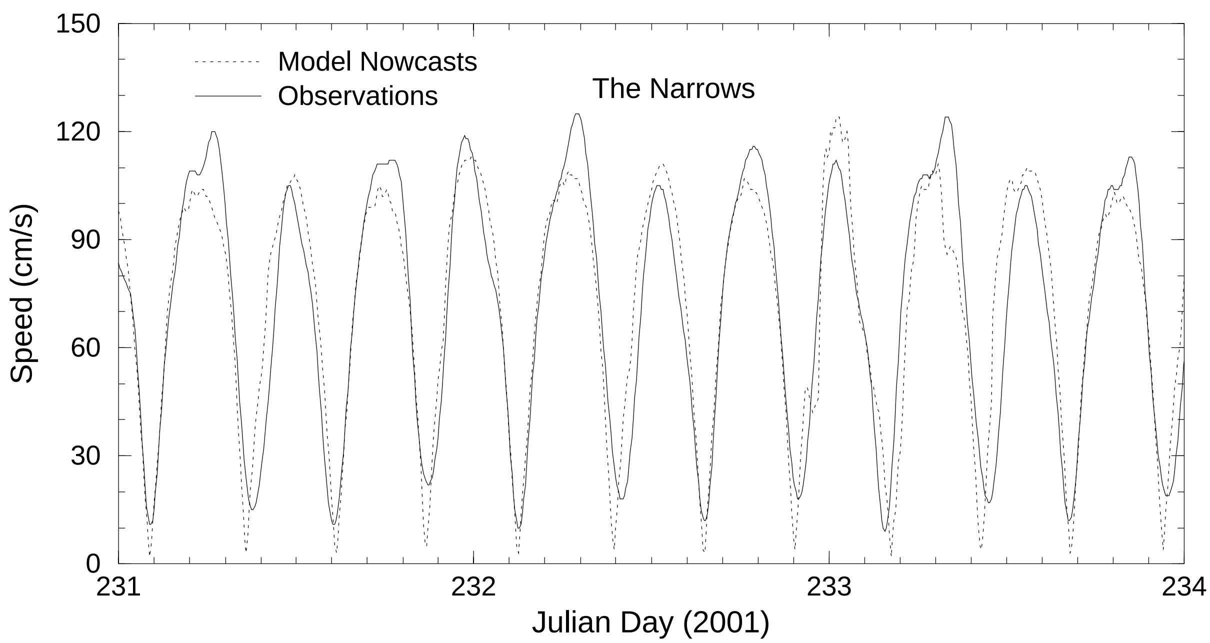


Figure 4.6. Observed (low-passed) and model nowcast current speed time series at The Narrows, August 20 - 23, 2001.

Table 4.20. Current speed and direction nowcast skill assessment standard suite statistics at The Narrows, based on 18,985 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Acceptance Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	58.1	57.9	-0.22	240.2	243.6	3.3	na
SD (cm/s) (deg)	na	na	13.1	na	na	11.5	na
RMSE (cm/s) (deg)	na	na	13.	na	na	12.0	na
CF (26 cm/s) (22.5 deg)%	94.7			95.2			≥ 90
POF (52 cm/s)(45 deg) %	0.0			0.8			≤1
NOF (52 cm/s) (45 deg)%	0.0			0.0			≤1
MDPO (52 cm/s) (45 deg)(Hour)	3			4			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			1			≤ 24

Nowcast Current Slack Time at The Narrows

The skill assessment for the beginning and end time of SBE and SBF series at The Narrows are computed. The observed and model simulated current nowcasts have 2 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 3 continuous time series segment and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between observed and model-based tidal currents. Table 4.21 lists the statistical parameters for The Narrows. Although the statistics are better than that at Bergen Point, the slack time performance is still below NOS acceptable criteria. When the criteria were relaxed (the time limit was doubled), the skills of CF, POF, and NOF are improved, although they are still below the criteria.

Table 4.21. Skill assessment standard suite statistics for the beginning and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (bin 20) and forecasts (layer 2) at The Narrows. Statistics below the double line represent the time limit criteria was doubled. (Note: na = not applicable)

	The Narrows		NOS Accepted Criteria
	SBE	SBF	
SM (minutes)	-0.2	-27.7	na
SD (minutes)	13.2	19.8	na
RMSE (minutes)	13.1	34.1	na
CF (15 minutes) %	78.2	26.0	≥ 90
POF (30 minutes) %	1.3	0.0	≤1
NOF (30 minutes) %	1.7	41.0	≤1
MDPO (30 minutes)	1	0	≤3
MDNO (30 minutes)	1	7	≤3
CF (30 minutes) %	97.0	58.7	
POF (60 minutes) %	0.0	0.0	
NOF (60 minutes) %	0.0	7.1	

Nowcast Maximum Flood and Ebb Currents at The Narrows

Although these are not required by NOS (1999), the model nowcast time, speed, and direction of maximum flood and ebb currents at The Narrows are also compared with observations to evaluate the model system performance. Table 4.22 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.22 shows that the CF for the speed and direction of maximum currents are 100% indicating that the model performs well in defining the maximum current speeds and directions. However, the simulated time of maximum flood current lags behind the observations by about 36 minutes (RMSE) as shown in Figure 4.6.

Table 4.22. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (bin 20) and nowcasts (layer 2) at The Narrows. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	-17.0	2.7	7.6	-9.0	-12.6	-4.0
SD (min) (cm/s) (deg)	31.9	6.7	6.5	35.3	6.8	8.9
RMSE (min) (cm/s) (deg)	36.0	7.2	10.0	36.1	14.4	9.8
CF (30 min) (26 cm/s) (22.5 deg)%	61.5	100.0	100.0	61.7	99.3	100.0
POF (60 min) (52 cm/s)(45 deg) %	0.0	0.0	0.0	1.3	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	7.4	0.0	0.0

4.6. Skill Assessment for Current Forecasts

Forecast Current Speed and Direction Skill Assessment at Bergen Point

ADCP current observations about 4 m below the water surface (bin 8) are compared with simulated current speed and direction forecasts (05z cycle only) at the equivalent depth (find-grid model layer 3) at Bergen Point from October 6 to December 3, 2000. The observations are low-pass filtered with a 90 minute filter to remove high frequency disturbances. Selection of both the observed and modeled co-existing data results in over 11,000 total valid 6-minute samples, equivalent to about 48 days. The time difference (2 minutes) between simulated and observed data time has been neglected in calculating the statistics. The current speed time series between October 6 to 11, 2000 is shown in Figure 4.7. The model forecast current speed time series (Figure 4.7) are very similar to the nowcast (Figure 4.5). The parameters in the analysis are obtained based on the entire data set except for MDPO and MDNO, which are based on each continuous data set.

Current speed and direction skill assessments for Bergen Point are listed in Table 4.23. The statistics are very similar to the nowcasts (Table 4.17). The current speed CF (75.9%) is below the NOS acceptable criterion (90%). Tables 4.24 and 4.25 lists the 24 hour current speed and direction forecast statistics. The speed CF ranges from 65% to 84% throughout the 24 forecast hours, but not necessarily degrading with time. The POFs are greater than 1% for all forecast hours, however, most of the NOFs are less than 1%.

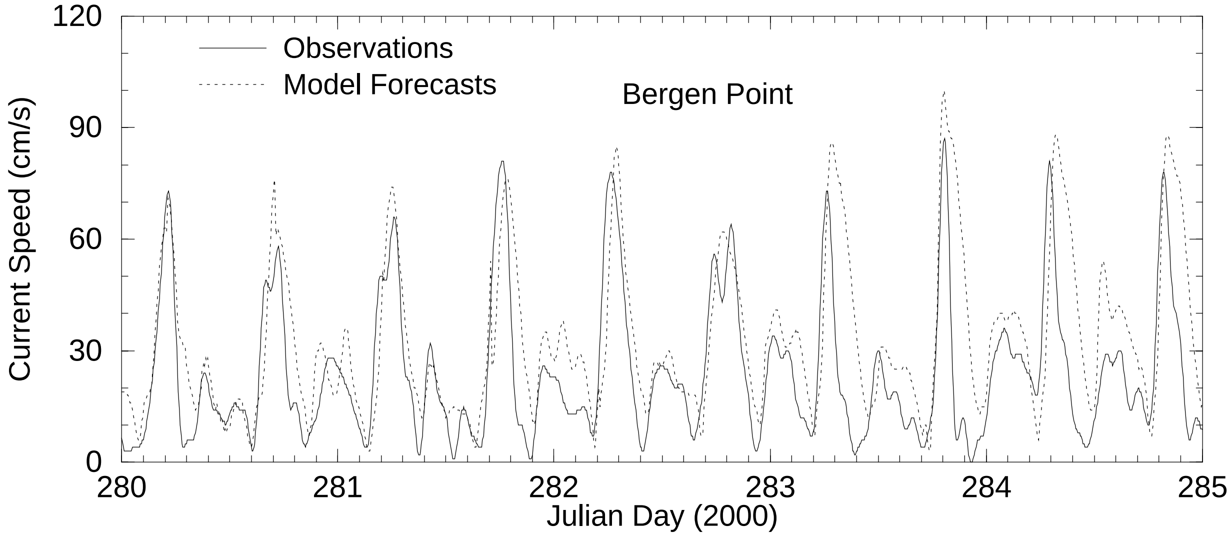


Figure 4.7. Observed (low-passed) and model forecast current speed time series at Bergen Point, October 6 - 11, 2000.

Table 4.23. Forecast current speed and direction skill assessment standard suite statistics at Bergen Point, based on 11,674 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	28.2	44.2	16.0	228.9	232.5	3.6	na
SD (cm/s) (deg)	na	na	21.2	na	na	16.4	na
RMSE (cm/s) (deg)	na	na	26.6	na	na	16.9	na
CF (26 cm/s) (22.5 deg)%	75.9			85.4			≥ 90
POF (52 cm/s)(45 deg) %	8.0			0.3			≤1
NOF (52 cm/s) (45 deg)%	0.0			0.6			≤1
MDPO (52 cm/s) (45 deg)(Hour)	22			3			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	3			8			≤ 24

Table 4.24. Model system current speed forecast statistics at each of the 24 forecast hours at Bergen Point. (Note: Overall RMSE average: 26 cm.s^{-1})

Forecast Hour	CF (26 cm s^{-1})	POF (52 cm s^{-1})	NOF (52 cm s^{-1})	RMS (cm s^{-1})
1	81.1	2.3	0.0	20.6
2	82.6	3.8	0.0	22.0
3	73.5	6.8	0.0	25.2
4	71.2	5.3	0.0	26.3
5	68.2	9.8	0.0	29.6
6	71.2	12.9	0.8	31.5
7	65.2	15.9	0.0	33.1
8	65.2	6.1	1.5	29.9
9	73.5	9.1	0.8	26.9
10	77.3	4.5	0.0	24.0
11	81.8	1.5	0.0	22.1
12	75.0	6.8	0.0	25.7
13	78.0	2.3	0.0	22.8
14	81.1	6.1	0.0	23.1
15	75.8	5.3	0.0	24.0
16	70.5	9.1	0.0	27.3
17	68.2	11.4	0.0	30.8
18	70.5	15.2	0.0	32.5
19	69.7	11.4	0.0	29.8
20	66.7	5.3	1.5	28.3
21	75.0	9.1	1.5	26.6
22	80.3	3.8	0.0	23.6
23	82.6	2.3	0.0	20.9
24	84.8	0.0	1.5	19.2

Table 4.25. Model system current direction forecast statistics at each of the 24 forecast hours at Bergen Point. (Note: Overall RMSE average: 20.0 degrees)

Forecast Hour	CF (22 deg)	POF (45 deg)	NOF (45 deg)	RMSE (deg)
1	78.6	2.9	0.0	19.5
2	84.3	0.0	0.0	17.9
3	87.0	1.4	0.0	16.9
4	79.2	1.4	1.4	19.9
5	79.4	1.5	1.5	18.7
6	76.3	3.4	3.4	20.5
7	83.6	1.8	0.0	17.6
8	80.4	1.8	1.8	29.5
9	75.4	1.8	0.0	19.6
10	76.8	4.3	0.0	20.0
11	87.7	0.0	1.5	18.4
12	77.4	0.0	0.0	18.3
13	82.1	0.0	0.0	16.0
14	84.0	1.3	0.0	17.3
15	84.5	0.0	1.4	16.0
16	83.3	1.5	1.5	18.6
17	76.9	1.5	3.1	20.1
18	83.6	0.0	0.0	16.2
19	77.2	0.0	0.0	18.9
20	74.1	3.7	1.9	43.2
21	81.1	0.0	0.0	18.2
22	88.9	1.6	0.0	15.7
23	80.0	0.0	0.0	16.8
24	79.2	0.0	0.0	16.8

Forecast Current Slack Time at Bergen Point

The skill assessment for the beginning and end time of SBE and SBF series at Bergen Point are computed. The observed and model simulated current forecasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segments and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between the observed and the model-based forecast currents. Table 4.26 lists the statistical parameters for Bergen Point. Similar to the nowcast, the forecast current slack time statistics do not meet NOS standards due to the complex flow pattern and horizontal current shears near Bergen Point. The skills of CF, POF, and NOF have been improved, although still below the criteria, when the criteria was doubled (relaxed) (below the double line in Table 4.26).

Table 4.26. Skill assessment standard suite statistics for begin and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (bin 20) and forecasts (fine grid layer 2) at Bergen Point. Statistics below the double line represent the time limit criteria was doubled. (Note: na = not applicable)

	The Narrows		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	28.7	33.5	na
SD (minutes)	64.4	38.0	na
RMSE (minutes)	70.4	50.6	na
CF (15 minutes) %	8.7	24.0	≥ 90
POF (30 minutes) %	49.3	42.5	≤1
NOF (30 minutes) %	14.0	1.4	≤1
CF (30 minutes) %	36.7	56.2	
POF (60 minutes) %	37.3	21.2	
NOF (60 minutes) %	4.7	0.0	

Forecast Maximum Flood and Ebb Currents at Bergen Point

The model forecast time, speed, and direction of maximum flood and ebb currents at Bergen Point are also compared with the observations to evaluate the model system performance. Table 4.27 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.27 shows statistics of the time, speed, and direction of the maximum currents. The CF of maximum current speeds and directions are near of above 88% except maximum flood current speed (65%). The forecast time of maximum flood current lags behind the observations by greater than 30 minutes RMSE.

Table 4.27. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (bin 20) and forecasts (fine grid layer 2) at Bergen Point. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	44.2	23.6	10.2	10.5	11.6	-1.9
SD (min) (cm/s) (deg)	27.4	13.4	2.4	79.2	7.1	14.5
RMSE (min) (cm/s) (deg)	52.0	27.1	10.4	79.2	13.5	14.5
CF (30 min) (26 cm/s) (22.5 deg)%	36.1	65.1	100.0	28.3	98.3	88.3
POF (60 min) (52 cm/s)(45 deg) %	31.3	2.4	0.0	36.7	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	18.3	0.0	0.0

Forecast Current Speed and Direction at The Narrows

The current forecasts from the experimental model system (coarse grid) at The Narrows from August 20 to November 30, 2000 are compared with observations. Adjusting both forecasts and observations, based on data gaps, results in near 19,000 records of 6 minutes samples of forecasts in model layer 2 and observations in bin 20. The time difference for each corresponding forecast and observation record is about 2 to 3 minutes, which has been neglected in the analysis. Current speed and direction skill assessments for The Narrows are listed in Table 4.28. The statistics are very similar to the nowcasts (Table 4.20). All parameters satisfy NOS criterion except for the POF (2.2%) direction statistic.

Table 4.28. Current speed and direction forecast skill assessment standard suite statistics at The Narrows, based on 18,935 six minute interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	56.1	56.5	0.4	238.1	238.3	5.6	na
SD (cm/s) (deg)	na	na	13.1	na	na	24.1	na
RMSE (cm/s) (deg)	na	na	13.	na	na	24.1	na
CF (26 cm/s) (22.5 deg)%	95.1			92.0			≥ 90
POF (52 cm/s)(45 deg) %	0.0			2.2			≤1
NOF (52 cm/s) (45 deg)%	0.0			0.2			≤1
MDPO (52 cm/s) (45 deg)(Hour)	2			14			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0			6			≤ 24

The statistics, including CF, POF, NOF, and RMSE, for the current speed forecasts at The Narrows at each of the 24 forecast hours are calculated and listed in Table 4.29. Most of the central frequency (CF) are either exceeding or close to the NOS (1999) criteria. The outliers (POF and NOF) also pass the NOS standards, except for POF at Forecast hour 20 (1.3%). This indicates that the model forecast current speeds at The Narrows are very accurate. Table 4.30 lists the 24 hour forecast statistics for the direction. The RMSE of the direction is 24.1 degrees. The statistics either exceed or are close to the NOS (1999) criteria.

Table 4.29. Model system current speed forecast statistics at each of the 24 forecast hours at The Narrows. (Note: Overall RMSE average: 13 $cm.s^{-1}$)

Forecast Hour	CF ($26\ cm\ s^{-1}$)	POF ($52\ cm\ s^{-1}$)	NOF ($52\ cm\ s^{-1}$)	RMSE ($cm\ s^{-1}$)
1	96.1	0.0	0.0	14.3
2	96.1	0.0	0.0	11.4
3	97.4	0.0	0.0	11.2
4	97.4	0.0	0.0	11.9
5	96.1	0.0	0.0	12.0
6	96.1	0.0	0.0	12.2
7	89.6	0.0	0.0	15.2
8	90.9	0.0	0.0	15.2
9	98.7	0.0	0.0	11.3
10	100.0	0.0	0.0	10.5
11	100.0	0.0	0.0	9.8
12	97.4	0.0	0.0	11.0
13	94.8	0.0	0.0	13.0
14	100.0	0.0	0.0	11.2
15	98.7	0.0	0.0	11.4
16	97.4	0.0	0.0	11.7
17	97.4	0.0	0.0	13.3
18	100.0	0.0	0.0	12.0
19	96.1	0.0	0.0	13.6
20	88.3	1.3	0.0	17.0
21	87.0	0.0	0.0	17.4
22	87.0	0.0	0.0	16.9
23	90.9	0.0	0.0	13.5
24	96.1	0.0	0.0	12.6

Table 4.30. Model system current direction forecast statistics at each of the 24 forecast hours at The Narrows. (Note: Overall RMSE average: 24.1 degrees)

Forecast Hour	CF (22 deg)	POF (45 deg)	NOF (45 deg)	RMSE (deg)
1	90.0	3.3	0.0	38.3
2	93.1	1.7	0.0	14.2
3	88.7	1.6	0.0	17.9
4	95.1	0.0	0.0	11.3
5	95.1	0.0	0.0	10.8
6	100.0	0.0	0.0	9.0
7	95.0	1.7	0.0	12.4
8	90.2	0.0	0.0	12.4
9	88.9	1.6	0.0	25.8
10	93.7	0.0	0.0	11.7
11	89.2	3.1	0.0	26.0
12	92.1	1.6	0.0	23.8
13	92.2	0.0	0.0	13.2
14	89.2	3.1	0.0	16.5
15	87.5	3.1	0.0	17.8
16	95.1	0.0	0.0	12.3
17	90.6	4.7	0.0	16.6
18	95.3	1.6	0.0	12.7
19	96.8	0.0	0.0	11.8
20	91.7	3.3	0.0	33.6
21	89.2	4.6	0.0	39.4
22	88.5	4.9	0.0	63.7
23	88.5	1.6	0.0	27.9
24	93.0	1.8	1.8	16.6

Forecast Current Slack Time at The Narrows

The skill assessment for the beginning and end time of SBE and SBF series at The Narrows are computed. The observed and model simulated current forecasts have 3 gaps. Therefore, the beginning and end time of SBE and SBF are selected from each of 4 continuous time series segment and then put together. Two sets of standard NOS statistics are then computed based on the differences of SBE and SBF beginning and end times between observed and model-based forecast currents. Table 4.31 lists the statistical parameters for The Narrows. The statistics are better than that at Bergen Point, however, they still do not meet NOS standard. The skills would be improved dramatically if the criteria was doubled (relaxed) (below the double line in Table 4.31.

Table 4.31. Skill assessment standard suite statistics for beginning and end times of SBE (slack before ebb) and SBF (slack before flood) differences between current observations (bin 20) and forecasts (coarse grid layer 2) at The Narrows. Statistics below the double line represent the time limit criteria was doubled. (Note: na = not applicable)

	The Narrows		
	SBE	SBF	NOS Accepted Criteria
SM (minutes)	2.3	-24.2	na
SD (minutes)	16.0	22.4	na
RMSE (minutes)	16.1	33.0	na
CF (15 minutes) %	66.6	33.5	≥ 90
POF (30 minutes) %	3.3	0.3	≤1
NOF (30 minutes) %	4.6	35.2	≤1
CF (30 minutes) %	92.1	64.4	
POF (60 minutes) %	0.0	0.0	
NOF (60 minutes) %	0.0	5.0	

Forecast Maximum Flood and Ebb Currents at The Narrows

The model forecast time, speed, and direction of maximum flood and ebb currents at The Narrows are also compared with observations to evaluate the model system performance. Table 4.32 shows the skill statistics in terms of CF, RSME, POF, and NOF. Note that the criteria variable for time has been set to 30 minutes.

Table 4.32 shows that the CF for the speed and direction of maximum currents are near 100%, except maximum ebb direction (87.9%), indicating that the model performs well in defining the maximum current speeds and directions. However, the forecast time of maximum flood current lags behind the observation by greater than 30 minutes (RMSE).

Table 4.32. Skill assessment standard suite statistics for maximum current time, speed, and direction differences between current observations (at bin 20) and forecasts (in layer 2) at The Narrows. (Note: na = not applicable)

	Maximum Flood Current			Maximum Ebb Current		
	Time	Speed	Direction	Time	Speed	Direction
SM (min) (cm/s) (deg)	-19.6	9.9	0.3	-11.8	-6.3	-11.1
SD (min) (cm/s) (deg)	34.3	6.6	8.4	30.8	8.2	9.1
RMSE (min) (cm/s) (deg)	39.4	11.9	8.4	32.9	10.3	14.4
CF (30 min) (26 cm/s) (22.5 deg)%	47.6	99.3	99.3	61.1	98.7	87.9
POF (60 min) (52 cm/s)(45 deg) %	0.0	0.0	0.7	0.7	0.0	0.0
NOF (60 min) (52 cm/s) (45 deg)%	0.0	0.0	0.0	4.0	0.0	0.0

4.7. Comparison of Coarse Grid and Find Grid Currents

A nested grid model with one-way coupling method such as NYEFS produces water levels and currents at grid locations over both the fine grid area. The semi-operational coarse grid nowcast and forecast currents at individual locations were not archived; therefore, the model data from the yearly (1997) hindcast simulation reported in Wei and Chen (2001) are used for the comparison of skills between the coarse grid and the fine grid. It has been shown that the water level difference between the coarse grid and the fine grid at Bayonne Bridge are insignificant (Table 4.33). However, it may not be true for the currents.

Tables 4.34 and 4.35 show the fine grid current speed and direction skill assessment at the Bayonne Bridge and Bergen Point (Wei and Chen, 2001). Tables 4.36 and 4.37 show the skill assessment at the same locations from the coarse grid. At the Bayonne Bridge, the skills are about the same for the speed and direction from both model grids due to a rectilinear flow along the straight Kill Van Kull navigation channel. However, the fine grid skill at Bergen Point is better than that for the coarse grid for not only the speed but also the direction. This is expected since the fine grid model is more capable of resolving the horizontal flow shear and the eddy near the area.

Table 4.33. Water level hindcast skill assessment standard statistics for complete time series at Bayonne Bridge. (Note: na = not applicable)

	Fine Grid			Coarse Grid			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm)	7.6	9.9	2.3	7.6	10.6	3.0	na
SD (cm)	na	na	8.2	na	na	8.0	na
RMSE (cm)	na	na	8.6	na	na	8.6	na
CF (15 cm) %	91.5			92.0			≥ 90
POF (30 cm) %	0.7			0.5			≤1
NOF (30 cm) %	0.1			0.0			≤1
MDPO (30 cm) (Hour)	7			7			≤ 24
MDNO (30 cm) (Hour)	2			1			≤ 24

Table 4.34. Fine Grid current speed and direction hindcast skill assessment standard suite statistics at Bayonne Bridge, based on 29,806 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	53.6	56.8	3.2	183.9	174.2	-9.7	na
SD (cm/s) (deg)	na	na	18.8	na	na	23.6	na
RMSE (cm/s) (deg)	na	na	19.1	na	na	25.6	na
CF (26 cm/s) (22.5 deg) %	82.8			93.3			≥ 90
POF (52 cm/s)(45 deg) %	1.1			0.4			≤1
NOF (52 cm/s) (45 deg) %	0.5			1.4			≤1
MDPO (52 cm/s) (45 deg) (Hour)	1.5			1.4			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	1.7			0.9			≤ 24

Table 4.35. Fine Grid current speed and direction hindcast skill assessment standard suite statistics at Bergen Point, based on 14,158 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	31.1	41.5	10.4	278.3	271.9	-6.4	na
SD (cm/s) (deg)	na	na	18.5	na	na	46.4	na
RMSE (cm/s) (deg)	na	na	21.2	na	na	46.8	na
CF (26 cm/s) (22.5 deg) %	83.9			77.3			≥ 90
POF (52 cm/s)(45 deg) %	3.6			1.6			≤1
NOF (52 cm/s) (45 deg) %	0.1			6.1			≤1
MDPO (52 cm/s) (45 deg) (Hour)	2.5			0.7			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	0.5			1.9			≤ 24

Table 4.36. Coarse Grid current speed and direction hindcast skill assessment standard suite statistics at Bayonne Bridge, based on 29,806 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	53.6	44.3	-9.3	183.9	179.8	-4.0	na
SD (cm/s) (deg)	na	na	16.8	na	na	20.8	na
RMSE (cm/s) (deg)	na	na	19.2	na	na	21.2	na
CF (26 cm/s) (22.5 deg)%	84.5			95.0			≥ 90
POF (52 cm/s)(45 deg)%	0.0			0.4			≤1
NOF (52 cm/s) (45 deg)%	1.4			1.1			≤1
MDPO (52 cm/s) (45 deg)(Hour)	0.0			1.9			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	2.4			0.9			≤ 24

Table 4.37. Coarse Grid current speed and direction hindcast skill assessment standard suite statistics at Bergen Point, based on 14,158 six minutes interval data**.** (Note: na = not applicable)

	Speed			Direction			NOS Accepted Criteria
	Observed	Model	Difference	Observed	Model	Difference	
SM (cm/s) (deg)	31.1	26.0	-5.0	278.3	274.2	10.8	na
SD (cm/s) (deg)	na	na	22.9	na	na	33.8	na
RMSE (cm/s) (deg)	na	na	23.4	na	na	35.4	na
CF (26 cm/s) (22.5 deg)%	73.5			49.4			≥ 90
POF (52 cm/s)(45 deg)%	0.0			2.3			≤1
NOF (52 cm/s) (45 deg)%	2.6			5.6			≤1
MDPO (52 cm/s) (45 deg)(Hour)	0.1			1.6			≤ 24
MDNO (52 cm/s)(45 deg) (Hour)	2.8			2.0			≤ 24

5. SUMMARY

An experimental nowcast/forecast water level and current model system for the Port of New York/New Jersey has been operational on CSDL computers since April, 1999. The model system performs hourly nowcasts using observed water levels at Sandy Hook, NJ and Kings Point, NY, as the lateral open boundary condition. The observed winds at Sandy Hook, NJ, Bayonne Bridge, NY, Robbins Reef, NY, and Kings Point, NY, are used as model surface forcing. The nowcast model fields at 05Z and 17Z are used for 36 hours model forecast runs forced with Eta winds and ETSS water level forecasts. The modeled water levels at the Bayonne Bridge and The Battery, and the observed currents at Bergen Point, Bayonne Bridge, and The Narrows are used for the model system skill assessment.

The skill assessment results indicate that most parameters for the water level nowcasts either exceed, or are close to the NOS (1999) criteria. Due to the inaccuracy of subtidal water level forecasts from ETSS at Sandy Hook and Kings Point, the CF of model simulated water levels at most of forecast hour are below NOS (1999) criteria. The current velocity nowcasts and forecasts at The Narrows, although from the coarse grid, are better modeled than at Bergen Point from the fine grid because of geometry complexity near Bergen Point.

The model system uses the three-dimensional barotropic version of POM. Therefore the effects of density are not included. In the near future, the barotropic model will be extended to include the salinity and temperature since commercial ship operations require the water density information for maximizing the cargo loading, and avoiding potential grounding. The salinity and temperature information will not only be useful for navigational safety and efficiency, but will also be the key parametric input for water quality and environmental requirements.

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REFERENCES

Black, T.L., 1994. The new NMC mesoscale Eta model: Description and forecast examples. **Weather and Forecasting,** 9, pp. 265-278.

Blumberg, A.F. and G.F. Mellor, 1987. A Description of a Three-dimensional Coastal Ocean Circulation Model. In: **Three-dimensional Coastal Ocean Models**, Coast and Estuarine Science, Vol. 4 (Heaps, N.S. ed.), American Geophysical Union, Washington, D.C., 1-16.

Chen, J., W. Shaffer, and S. Kim, 1993. A forecast model for extra-tropical storm surge. **Advances in HydroScience and Engineering**. Vol. 1, pp. 1437-1444.

Evans, Michael, Geoffrey French, and Thomas Bethem, 1998. Information System Branch PORTS Uniform Flat File Format (PUFFF). Unpublished Report, Oceanographic Products and Services Division/Information Systems Branch, NOAA/NOS, Silver Spring, Maryland, 28p.

Kelley, J.G.W., E. Wei, S. Maxwell, A. Thompson, and M. Westington, 2000. Description of the Operational data Acquisition and Data Archive System. (ODAAS) to support the NOS Chesapeake Bay Operational Forecast System (CBOFS). **NOAA Technical Report**, NOS CO-OPS 0021, NOAA/NOS, 33p.

Kim, S.-C., J. Chen, and W.A. Shaffer, 1996. An operational forecast model for extratropical storm surges along the U.S. east coast. **Preprints Conference on Coastal Oceanic and Atmospheric Prediction,** Atlanta, Amer. Meteor. Soc., 281-286.

National Ocean Service (NOS), 1999. NOS Procedure for Developing and Implementing Operational Nowcast and Forecast System for PORTS, **NOAA Technical Report**, NOS CO-OPS 0020, NOAA/NOS, 33p.

Wei, E. and M. Chen, 2001. Hydrodynamic Model Development for the Port of New York/New Jersey Water Level and Current Nowcast/Forecast Model System , **NOAA Technical Report,** NOS CS 012, NOAA/NOS, 46p.